

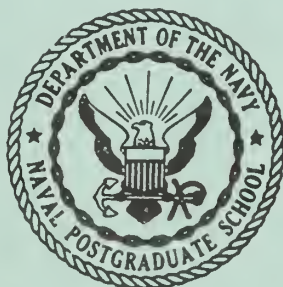
DESIGN AND ANALYSIS OF A NAVIGATION
PANEL LAYOUT BASED ON A
METHODOLOGICAL APPROACH

JOHN H. SPILLER, JR.

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THESIS

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Submitted in partial fulfillment of
the requirements for the degree of

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ABSTRACT

The need for human engineering techniques is discussed, and three available methods of man-machine systems analysis presented. To serve as an example of how these methods of analysis can be employed to assist in producing superior equipment design, a prototype aircraft control panel is analyzed using three of the discussed techniques. A redesign was then performed and subjected to the same analyses. A comparison of the two designs was made showing the superiority of the redesigned control panel.

This work was performed during the author's industrial tour at Litton Industries, Canoga Park, California, during the period 4 January to 10 March, 1960, while a student at the U.S. Naval Postgraduate School.

The author wishes to express his deep appreciation to Professors A. Sheingold and M. L. Cotton of the U.S. Naval Postgraduate School for their encouragement and many helpful suggestions, as well as for their consideration and time. The author wishes to extend his appreciation to Mr. David M. Piatt and the entire Human Factors Group of Litton Industries for their help and guidance in the integration of electronic and human engineering.

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1. Introduction

The author was associated with the design, development, and prototype construction of several elements of the Carrier Based-Airborne Tactical Data System (CB/ATDS) designated as the AN/ASA-27 system for the U. S. Navy. One component of the equipment under development is designated the Navigation Control Panel. This panel is located in the pilot's compartment of a W2F type aircraft. In general, its function is to provide information to the pilot concerning patrol station keeping, in-transit position, true aircraft track and other associated data. Pilot requirements are to supply a special purpose computer with fixed data inputs, such as destination and barrier reference point latitude and longitude. All navigational computations are to be performed by the Navigation Computer and the results displayed to the pilot on request. The Navigation Control Panel is to serve as the pilot-to-machine link for this airborne computer. The importance of this instrument is readily apparent, since the safe navigation and proper conduct of the mission of the aircraft are dependent upon it correctly fulfilling its function.

Based on the significance of the navigation panel in the overall conduct of the aircraft's mission, an extensive investigation of its task performing abilities is required. This investigation consists of three distinct phases. Phase I is an analysis and evaluation of Prototype Navigation Panel No. 1 which has been designed as a part of the first prototype of the entire system. This phase of the investigation is to determine the adequacy of the existing panel to perform its function with respect to control and indicator requirements. Phase II consists of an employment of methodological approaches to

design a new panel to fulfill the requirements and overcome the inadequacies revealed by Phase I in the prototype No. 1 model. The same design constraints applicable when panel No. 1 was designed apply to the design of the new panel.¹ Phase III is a complete analysis and evaluation of the new panel arrangement using the same criterion established during the investigation conducted in Phase I.

The work performed under this study reflects an attempt to incorporate several established concepts of modern experimental psychology into the design phase of an electronic engineering problem. Basically, the approach involves a careful analysis of human factor considerations simultaneously with engineering feasibility. By basing the design process on such an analysis it is felt that the resultant system design approaches an optimum for the present "state of the art". As an example for evolution, the resultant design is compared with an earlier engineering solution.

¹These design constraints are weight, size, location, and customer specification.

2. Human Engineering and the Methodological Approach

Human engineering is the name applied to that branch of modern technology which deals with ways of designing machines, operations, and work environments so that they match human capacities and limitations . . . human engineering is concerned with the engineering of machines for human use and the engineering of human tasks for operating machines. [3]

In a literal sense human engineering originated when the first machines were conceived by man. The necessity that machines be capable of use by human operators was inherent in their conception. This is a basic principle of human engineering. From this early beginning until only recently, the formalized concepts of human engineering lay dormant in the background of machine design. There are many examples of machines rated as excellent, from a human engineering point of view, that developed without the direct employment of human engineering methods. The telephone¹ and present day bicycle are in this category. At the end of the 19th century psychologists (among others) recognized the need for understanding more completely the individual and his relation to his environment.² However, this work was largely overlooked by equipment designers for 60 years.

1 The present telephone receiver-transmitter handset represents a near optimum match between man and machine. However, the telephone also serves as an excellent illustration of the application of human engineering technology. A study was conducted a few years ago to determine the cause for the dialing of wrong numbers. It was determined that a major contributing factor was the placement of the letters and figures inside the circles used by the operator to dial. Once he had placed his finger in the hole the character selected was obscured and the selection process was abruptly terminated. To correct this defect a new design was developed with the letters and figures placed outside the dialing ring. In addition a small white dot was placed inside the circle, corresponding to each group of characters, to act as a target for the operator's finger. Tests conducted on this new design showed an improvement in the number of errors made in dialing. Considering the telephones in existence and the number of calls made yearly, this improvement represents a considerable savings in time and money [9] .

² W. Wundt founded the first psychological laboratory in Leipzig, Germany in 1879.

It took a major war to provide an appreciation and application of their studies.

Human engineering, as such, was non-existent prior to the 1940's primarily due to a lack of understanding the need for its technology. Engineers designed machines to meet specific requirements in terms of inputs and outputs and, using hunches, educated guesses, and/or intuition, were able to make them operable by human beings. A sort of "try-and-improve" system of successive approximations was evolved which eventually produced a machine within, or almost within, the capabilities and limitations of the man assigned to operate it. No deficiencies were noted in this procedure since the machines of this period were relatively simple. The method appeared reasonable and usually produced satisfactory results, and little or no attempt was made to improve it. With the great strides in the engineering sciences demanded by World War II, radically new and complex machines were developed. Following the usual design procedures, these machines were instrumented with controls and indicators of varying degrees of complexity as demanded by the equipment. Operators were instructed in the operation of these machines, given the training required, and the man and machine were then sent out into the field to realize the designed objectives. However, in many cases the results were far less satisfactory than anticipated. Reports from the field indicated that these new machines were operating below designed capabilities; something was wrong. From studies conducted by many different military groups, called in to determine the cause of these discouraging outcomes, a revealing trend was developed. The weak link in the system was the operator! The operator was unable to meet the demands of his equipment. The specific reasons varied from case to case. Sometimes it was the

inability to properly read visual displays -- misinterpretation of complicated instruments. In other instances, it was found that the operator could not respond quickly enough, or as accurately as required. Whatever the specific reasons were, the human operators were not able to meet the demands imposed by their machines. The "intuition-hunch-guess" method of design had failed; a new design approach was required. No longer could the old methods meet the requirements imposed by the advancing complexity of machine development.

The development of the airplane is a good illustrative example of how the need for human engineering manifested itself. In the early days of aviation there were few airplanes; the machine itself was simple and the selection of pilots no problem since learning to fly was relatively easy. As the science of aircraft design advanced, the machine became more complicated and the job of flying it increased proportionately. Due to this increase in complexity, greater care was required in the selection of capable pilots and more time and money was necessarily spent on their training. With the coming of World War II there arose a tremendous need for pilots and, to fulfill this need, selection standards had to be lowered. Also a revolution in design of aircraft to meet war requirements was taking place. Both of these factors combined to indicate a pressing need for a new appraisal of pilot¹ and aircraft relationship.

The aircraft was not the only machine to tax human capabilities; World War II produced many more. Electronic equipment, especially radar and sonar, were so complex that their full capabilities could not be

¹ Test batteries based on job analysis were developed by psychologists to select pilots, bombardiers, and navigators. They were singularly successful in that the students who scored in the upper ninth of their class could be trained successfully with less than 5% failures. Those students who were in the lower ninth of their class could not be successfully trained; over 90% of these students failed to pass their courses. Before the war was over there were many more able pilots available than aircraft. [23]

realized by the operators. Radar systems developed to a point where in a fraction of a second they could gather more information than their operators were capable of assimilating and acting upon. Sonar systems presented new requirements on human abilities to hear and perceive. Other machines such as fire control systems and complex communication equipment were taxing human abilities. The pressing needs of war for machines with **revolutionary capabilities**, longer ranges, higher power and greater sensitivity required maximum effort from the design engineer. Design engineers became so absorbed in their specialized problems that the "human machine" was virtually ignored. The consideration of the operator was obscured by the crash program to develop new and radical equipment to satisfy the demands of war.

To reiterate, towards the end of the war, it was obvious that man was the weak link in the man-machine complex. He could no longer effectively operate his equipment. In an attempt to find a solution to this rapidly increasing problem, it was necessary to pool the resources of scientists from many disciplines such as psychology, physiology, and **sociology**, as well as engineers. Although much of this sort of team work was performed too late to have any major effect during the war, the need for it was now evident.

The experimental psychologists had been working for years compiling data on man's capabilities. Of equal value to the knowledge gathered were the methods developed to obtain this knowledge. These methods of the experimental psychologists became the basis upon which the technology of present human engineering is founded. The time-and-motion engineers contributed much to the present state of the art but the experimental psychologist contributed the fundamental knowledge of human capacities and the methods of measuring human performance.

The solution to the dilemma of machines so complex that their operators could not effectively operate them manifested itself in two steps. The old method was machine-oriented design, where the machine rather than the man-machine system was emphasized in design. Little emphasis was placed on simplifying the job by modifying the machine to fit the man. This method was replaced by a man-oriented design in which emphasis was placed on both designing equipment to perform ever increasingly complex functions and providing for a high order of operator performance. However, this approach was prone to produce equipment that was difficult to maintain. From the man-oriented technique evolved the present concept of man-machine design. In the man-machine concept, instead of selecting the operator for the machine, or designing the machine around the operator, the human being is considered a part of the overall system with inputs, outputs, capacities and limitations. Adhering to this new approach, the designers became concerned with such problems as how the operator will react to given stimuli, his ease in operating and understanding instruments, and studies of his operating procedures. The effect on the operator and his ability to operate the machine became a prime consideration.

Over a period of time the people primarily concerned with man-machine relationships have become popularly known as human engineers.¹ While every designer of machines intended for human use employs some degree of "human engineering," it has been found necessary to create specialists² whose primary concern is human engineering. Today in an

¹ Human Engineers are also referred to as biomechanics engineers, biotechnologists, applied experimental psychologists, engineering psychologists, human factors engineers, and ergonomics engineers.

² The need for Human Engineering specialists is paralleled in other engineering specialties such as, computer, digital, analog, packaging, and heat.

organization set up to create complex man-machine systems, the human engineering group holds equal position with the system designer, component designer, mathematician and physicist. The application of human engineering technology is an essential part in the design of today's complex man-machine systems.

It is evident to even the most uninitiated, that today's modern aircraft carrier and its aircraft are highly complicated machines in themselves. When they are married to other complex machines and their missions, an overwhelming intricacy of man and machine results. To make such a man-machine complex even feasible, it is mandatory that optimum relations be achieved among all components of the complex. The aim of the present study is to achieve this optimum with two elements of such an assemblage. An approach, based on present human engineering technology, is employed to analyze, evaluate, and redesign an existing instrument in the pilot's compartment of a future AEW and Control aircraft. The analysis and evaluation is then performed on the new design and the results compared with the original design. The methods used encompass the latest "state of the art" technology of human engineering. While the study is primarily concerned with only two components, the pilot (man) and a navigation control panel (machine) of an overall complex, it is representative of the necessary approach required to develop the entire man-machine system to adequately carry out its mission.

While human engineering is destined to change with advances in machine design, there is one very important factor that tends to form a firm foundation for this new technology: Man. Man can be studied, measured, and reasonably predicted. His ability to see and hear, speed of reaction, correlative powers, agility and strength

are all reasonably fixed quantities.¹ Many of man's abilities and limitations have been exhaustively studied, categorized, and recorded. This wealth of information serves as a basis for human engineering application. However, some of the information is in such a form as to render it difficult for use by design engineers, and some critical areas are only sparsely covered.²

When machines were in their infancy and man was just learning to apply them to ease his daily tasks, there were only a few functions that these machines could do better than man himself. As he mastered the engineering sciences, this "balance of power" in the man-machine relationship shifted with each new technological advance. The ultimate aim of machine design is to be able to surpass man in all his functions; to date, this aim is far from realization. The present man-machine ability relationships, based on available information in psychology and physiology [8] is summarized as follows:

Sensory Ability: Except for the most complex instrumentation, the human sensing capacities of vision and audition surpass those of machines.

Perceptual Ability: Man excels at comprehending complex data presented by pictorial and symbolic displays.

Attention: By being alert for changes, human beings can effectively anticipate undesirable conditions.

Flexibility: Humans are characterized by a flexibility of action which provides insurance against complete system failure.

¹ Man's abilities, for the most part, have a distribution (usually normal) and a standard deviation, with position on the curve a function of such things as age, education, and social background.

² The important relationship between flicker of targets on a CRT display and operator performance has yet to be quantized.

Memory: Man is more efficient in tasks requiring long-term memory.

Judgment and Reasoning: Men are needed to make judgments when
it becomes impossible to reduce operations to
logical preset procedures.

Speed and Power: Machines can be devised to make movements more
smoothly, quickly, and powerfully than man.

Repetitive Operations: Machines excel in repetitive and routine
tasks; unlike humans, machines do not become
"bored or inattentive."

Computations: Machines designed to perform specific computing
operations are more efficient in this task
than men.

Simultaneous Actions: Machines can be devised to carry on a
greater number of simultaneous activities than
man.

This list forms a basis for the human engineer and equipment
designer of today for making decisions concerning the design of man-
machine systems. The list is not a fixed entity but subject to change
with the advent of a single scientific discovery or technological
advance.¹

¹ The light amplifier implies the ability for the machine "to see
better" than man, whereas present radars permit machines "to
see further" than man.

One of the practical objectives of human engineering is to provide basic data concerning human operators to assist engineers in designing equipment (usually part of a large man-machine system) that is adapted for efficient human use. Another objective is to determine what type of equipment needs to be developed in the first place. To provide a basis for deciding what machines should be developed, studies must be performed to determine which system functions should be assigned to human operators and which should be assigned to machines.¹ Criteria must be established to serve as a means of measuring the worth of a proposed or prototype system model. These criteria are based on the mission the man-machine system is designed to carry out. The methodological approaches to system analysis used in human engineering are designed to accomplish these objectives and produce the most efficient system of men and machines.

To date, there are four rather widely accepted methods of system analysis as well as one method developed by the Litton Human Factors Section: (1) system pictograms, (2) functional analysis, (3) link analysis, (4) decision analysis [13], and (5) Tentative Operational Procedures Chart (TOPC). The available literature on this subject is not uniform in the names given to these methods or even to their segregation, but, in general, the majority of techniques used to evaluate a man-machine system can be categorized under one or more of the above titles. While not all of these techniques will be used in the present evaluation-design problem, a brief discussion of each method will serve as a background to the types of analyses used.

¹ In addition to cost, weight, complexity and environment (to mention a few) the items listed on pages 9 and 10 are considered in these studies.

System Pictograms. A large complex system of men and machines can be represented by a chart or drawing. The major components of the system are presented and connected together with their proposed communication links. The overall requirements and missions of the system are indicated as well as the various functions of the subsystem components. Depending upon the degree of complexity other details may be included, such as, environment conditions, constraints on size and power, and emergency conditions. When this data is presented in the form of a large wall chart it is referred to as a system pictogram. Some advantages of the pictogram are: ease in grasping the concept of the overall problem, presenting an indication of the men and equipment involved and their inter-relationships, and some insight into how the system is proposed to function.

There are also several disadvantages to a pictogram. It is usually very general when applied to large systems or, if not general enough, the observer is confused by a mass of detailed information and loses grasp of what is trying to be presented. Also, not all the components that will eventually be incorporated in the system will find a place in the pictogram. Another disadvantage is that the pictogram does not show how each requirement of a system will be met. The main use of this type of analysis is to display an overall representation of the major inter-relations involved and conception of the man-machine system.

Functional Analysis. To obtain an insight into how the system is to function and how each requirement of a system will be met, a functional analysis is used. It consists of a detailed writeup of each requirement of the system and a diagram showing the various functions to be performed to meet these requirements and their inter-relationships.

Such an analysis will indicate areas of redundancy, weakness and bottlenecks of information flow, and overlapping of functions. From a study of the functional analysis can be derived the requirements of personnel and equipment for the system. What the functional analysis will not do is indicate the best arrangement of these men and machines. This type of analysis is most useful when applied to large scale systems during initial stages of conception.

Link Analysis. A method used to determine the best arrangement of components is the link analysis. It applies, equally well, to men and machines in a large system or to controls and indicators of a sub-system instrument. A link is a connection or tie between components of the system under consideration. Thus, an air-controller communicating with a pilot establishes a link between the air-controller and the pilot. It likewise establishes a link between the air-controller and his communication equipment, including the controls and dials on the transmitter and the transducer equipment (mike, speaker, headphones). The method of link analysis consists of representing all components under consideration by symbols and connecting them together with lines (links) that carry numbers representing the importance of each link. This link diagram is then analyzed and rearrangements made to produce the best configuration. Consideration is given to the weights each link carries with an aim of reducing distance and/or complexity of the heaviest weighted links at the expense of the weaker links. Thus, the results of a link analysis of a communications receiver would indicate the relative placement of the various controls and indicators (on-off, volume, tuning, etc.) to shorten time involved in operation and reduce operator errors.

Decision Analysis. A review of the above methods of analysis will indicate, among other things, the omission of a complete listing of the decision making processes involved in the system. In most information-handling systems (as opposed to mechanical operations like industrial assembly lines) decisions must be made at many points and by different components of the system. Decision analysis is a consideration of information flow, decisions made, and action taken. The decisions required in the system are listed and associated with their required information input and outputs. The information is arranged to indicate the sequence of decision-making activities. A decision analysis is a specialized type of analysis designed to focus attention on the decisions made in a system and the information required to make these decisions. From this analysis, critical decision areas are revealed and the adequacy of the required information appraised. Due to its limited scope, decision analysis is ordinarily not used alone, but it is considered in conjunction with other types of analysis, such as functional analysis.

Tentative Operational Procedures Chart (TOPC). The Tentative Operational Procedures Chart (TOPC)¹ is a powerful tool of systems analysis. It can be applied to systems of relatively large scope as well as single man-machine sub-systems. The TOPC combines many of the best features of the previously discussed analysis methods. The analysis and evaluation of the Navigation Control Panel employs a TOPC; for this reason and because of its general utility, a thorough description of a TOPC is presented. The TOPC is a five column chart (see Fig. 1) listing (1) operator procedures and criteria, (2) normal display and

¹ Tentative Operational Procedures Chart (TOPC) is a Litton Industries originated method of analysis.

STEP	OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIMES
Chronological order of steps	Describes each step that the operator performs, and criteria of performance	Describes the data displayed by the controls and indicators to the operator at each step	Explains the interaction between the operator and the equipment for each step (what the man does that affects the mechanism and what the mechanism does that influences the man's next step) . It covers both man to machine, and machine-to-man links.	The psychological process involved in the operator's behavior such as: perceptual, motor and cognitive	The time required for the man and the machine to perform each step

Figure 1 -- Format of a Tentative Operational Procedures Chart

control, (3) relational specifications, (4) psychological processes, and (5) performance times. In these five columns, are placed the pertinent data designed to permit an overall grasp of the system under consideration.

Operator procedures and criteria -- 1st column. This column contains a chronological list of the tasks performed by the operator in communicating to the machine.¹ A modified task analysis is presented, with each procedure described in detail. Conditions encountered in actual operational situations are normally assumed to exist in gathering the required information (i.e., many of the operator tasks listed in the TOPC constructed for the Nav-Panel are described as the pilot of the aircraft would normally perform them when airborne). As much detail as is consistent with the degree of analysis is included. In addition to knob-twisting, push-button and lever-operating tasks, operator discriminations, observations, computations, criteria and decision-making functions are also included. Many operator or machine tasks are conducted as adjustments (e.g., "adjust control until needle is peaked"), which employ feedback as the task is being conducted. By listing the criteria that will determine termination of specified tasks, a more complete analysis of the specified tasks may be realized. The statements describing the criteria must be detailed enough to reveal unrealistic or impossible processes. Statements such as, "turn oscillator tuning control, 'C' until output meter 'H' is peaked," are the type that would be

¹ Information required to set down operator tasks is derived from the "Functional Description." This document lists controls and indicators of a specific machine. Included is a description of how each control functions and how it is operated, and an explanation of each indicator and its intended use. Appendix A is the Functional Description of the Controls and Indicators for the W2F-1 Navigation Control Panel. The descriptions are exact and detailed enough so that the logical designers can use this document as a basis for their logical equations. The equipment is then designed to meet the logical equation requirements and thus the requirements of the human engineers who develop the functional description.

included. Statements as, "adjust oscillator tuning for maximum output" should be avoided, since they do not convey enough information for operator performance.

Normal display and control -- 2nd column. In this column are placed the results corresponding to the actions described in the 1st column, and the machine communications to the operator. Included are such items as changes that occur on the face of a control panel in response to some operator function or when the machine is communicating with the operator via a display indicator. This column is essentially a listing of the machine outputs to the operator that result from the operator inputs to the machine listed in column one.

Relational specifications -- 3rd column. Relational specifications are descriptions of the behavior of the machine resulting from the operator inputs. They are listed opposite (sequentially) each operator action, electrically or physically effecting the machine. They describe the means by which the man-machine "feedback loop" is accomplished. When columns 1, 2, and 3 are studied together, the signal flow from the operator's initial input, through the machine functions, to the machine indicator output to the operator can be traced, presenting a closed man-machine loop.¹ In addition, the effected machine loops are indicated for each operator-to-machine input. When the machine functions are too complicated to serve a useful purpose in the area of human factors work, they are outlined.

Psychological processes -- 4th column. This column classifies the operator's processes in terms of psychological categories. These categories have been identified by analytical and experimental studies

¹ The presence of this material, presented in easily understood phrases, is one reason why the completed TOPC provides an excellent basis for operator and training manuals.

and have been shown to be independent. Some of the more common ones are: auditory, vocal, motor responses (rate of arm movement, eye-hand coordination, etc.), perceptual and cognitive (deduction, memory and decision functions). The use of this column is derived from the factor tests that have been compiled for these various processes. A factor test permits the selection from a population of subjects those who are best suited to perform specified functions. And given a group of prospective operators, factor tests will indicate how they can be trained to maximize the efficiency of their operating procedures.

Performance times -- 5th column. In this column is recorded the times taken by the operator and machine to perform the functions listed in the 1st and 3rd columns. These times may run concurrently when both operator and machine tasks overlap. When measurement derived times are not available, best estimates are used. These times permit separate analysis of any portion of the system functions to determine where time delays are occurring.

There are many advantages to be gained from the study of a completed Tentative Operational Procedures Chart: (1) Evaluation of the man-machine system to determine adequacy of function assignment in meeting operational requirements, (2) Determination of omissions in the system, from mission and/or inadequate operator and machine inputs and outputs, (3) Evaluation of the adequacy of specific task assignments to human operators and machines, (4) Indication of improper or unrealistic distributions of man and machine activities, and (5) Determination of adequacy of machine controls and displays to meet operator needs and facilitate operator inputs to the system. It also provides, in one "basic" document, a description of how the system works from an operator's standpoint, including the functions carried out by the machine.

It ties together the operator's procedures and the machine procedures. The investigative processes required in constructing a TOPC in themselves provide much information concerning a man-machine system. The data gathering and recording gives a good insight into how the system is going to function. In many instances the construction of the TOPC will reveal most of the major inadequacies and short-comings of the man-machine system. In addition to its use in system analysis, the TOPC can be used in the preparation of instruction books, training and operator manuals.

The five types of analysis just described are basic methods presently used in man-machine system analysis. A most important point to be gained from these methodologies is perspective and balance to assist in determining the best possible design. Without it, "lopsided" and unrealistic operator tasks and machine functions may result. It should be emphasized that when the system under consideration has a **substantial** degree of complexity the execution of any one of these analyses may be realized only after many weeks or months of research and labor; however, the results obtained from a properly executed analysis will justify the effort expended.

Analysis of a large system composed of many men and machines normally are not as detailed as an analysis of a single man-machine system. Upon completion of a large-systems analysis, a more detailed analysis of limited scope must be conducted on the various sub-systems. The evaluation and investigation of a single man-machine sub-system may permit the use of various detailed and specific aspects of the basic methodologies most applicable to the smaller sub-system. Since these analyses are specific in their methodology they have been given descriptive names of their own. However, each is an extension and/or

specialization of the discussed methods. Some of the methods of analysis used on sub-systems are briefly discussed in the following paragraphs [13].

Flow analysis. A flow analysis presents the sequence of events in a system. It normally is composed of a coded chart depicting the flow of information between man and machines. It may include the element of time, if time is an important factor in the operation of the system. A flow analysis is useful for developing an overall picture of the information process in a system. From it can be derived the sequential distribution of operations, and the inputs and outputs of particular sub-systems. A study of a flow chart will indicate areas of man, machine, or man-machine overloading and under-loading, and suggest ways to rearrange the system to even the loads and reduce waiting times.

Activity analysis. An activity analysis is based on a single person in the system. It is a study of his various activities performed in carrying out his duties and consists of a listing of these activities in the sequence in which they occur. This list may be obtained by taking samples of the operator's functions on a time basis or sequence of activity basis. In either event it provides a useful means of determining how much time is spent doing what by the operator. Activity analyses provides information leading to changes in operational procedures, redesigning of equipment, and changes in distribution of duties.¹

Human Engineering Check List. Many of the control and display requirements of human operators in man-machine systems have been determined through experimental investigation. When those applicable

¹ All the major attributes of an activity analysis for a single man-machine sub-system are incorporated in a TOPC.

to a specific system are gathered together and presented in the form of a check list they serve as a means of equipment evaluation. The human engineering check list provides concise statements, concerning each type of control and indicator function, to assist the design engineer and system analyst in determining minimal requirements for configuration and functional design. A check list of this type, in general, can only indicate the most desirable features of design from the human operator's point of view. It is specific in nature, However, variation from it is possible (and sometimes desirable) with sufficient justification. When adequate reasons cannot be obtained in support of such variation a compromise design is indicated.

The foregoing is a representative cross-section of the methods of analysis in the field of human engineering as applied to systems and component equipment design. The present investigation is concerned with two components, considered as a sub-system of a vast complex of men and machines. A consideration of this sub-system (Pilot-Nav-Panel) indicated that three of the above discussed methodologies would produce an effective appraisal of the man-machine system. The analysis techniques used are (1) TOPC, (2) Link Analysis, and (3) Human Engineering Check List. The TOPC and link analysis tend to complement each other in usage and information derived, whereas the human engineering check list provides information that is specific in nature.

3. Formulation of requirements

The W2F-1 Navigation Control Panel is located in the pilot's compartment of the W2F-1 carrier based patrol aircraft. It is mounted just forward of the engine throttle controls on the left-hand side of the cockpit control pedestal. The primary mission of the Navigation Panel is to display navigation information to the pilot in usable and easily understood form. There are seven quantities that are required to be displayed on pilot request.

1. Wind direction and speed
2. Barrier reference point latitude and longitude
3. Barrier reference point to barrier center bearing and range
4. W2F-1 track angle and ground speed
5. Destination latitude and longitude
6. Destination range and bearing
7. Present position latitude and longitude

In addition to the display of navigation data there is a requirement for data entry. Five of the above quantities are derived from external sources and are initiated into the system by the pilot. These are:

1. Destination latitude and longitude
2. Barrier reference point latitude and longitude
3. Barrier reference point to barrier center bearing and range
4. Present position latitude and longitude
5. Wind direction and speed

For the present design problem, the above data entry requirements are considered "givens" in the sense that they are part of the specifications.

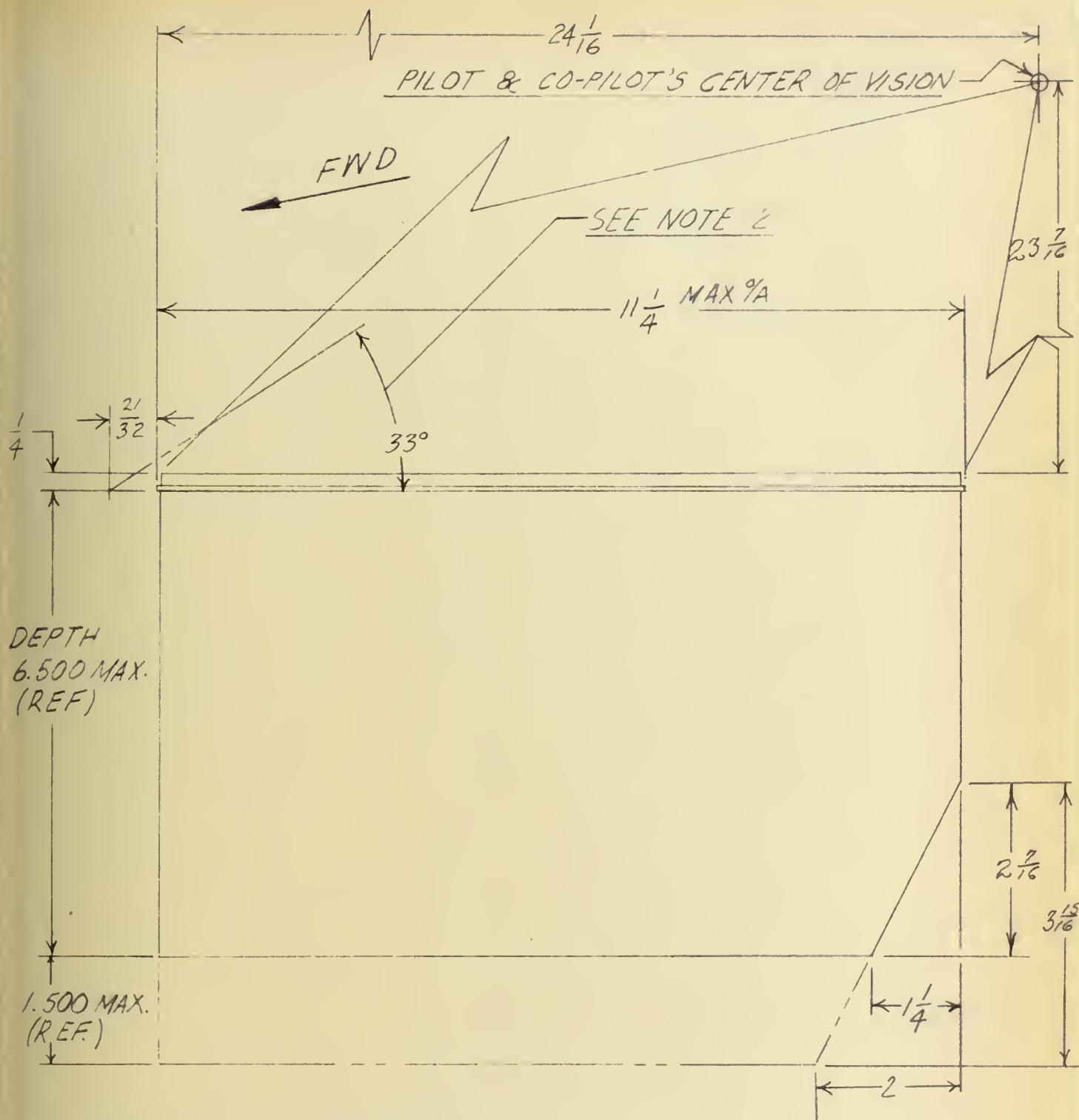
Most of the fundamental hardware specifications are detailed in Mil Spec 7788,¹ which lists general requirements for aircraft control

¹ Military Specification MIL-P7788, 23 October 1951

panels. Among the items that are specified are: selection of materials, design and construction restrictions, lighting and lettering, to mention just a few. Also included are the various environmental tests that must be satisfactorily passed. Mil Spec 7788 has been studied and its provisions constantly born in mind during the design work.

Particular to the Nav-Panel design are its dimension restrictions. These restrictions are indicated in Figure 2. They control very important design requirements for the panel. The volume of space occupied by the panel components and circuitry is definitely restricted. The electronics of the Nav-Panel must fit into the fixed panel dimensions. The space used for indicators and controls is likewise restricted by the available panel face area. In addition to the physical dimensions that restrict the panel there is a 33° line limiting the extent of indicators and controls as indicated on Figure 2. This 33° line of restriction is required because another piece of equipment (a small CRT display) is mounted above and forward of the Nav-Panel area.

In summary, the specified design requirements are (a) the displaying of 7 quantities that are available from a special purpose computer, (b) a means of data entry, or ability to change 5 of these quantities, (c) the necessity of meeting the volume specified, (d) specified area dimensions for controls and displays and (e) certain limiting restrictions on control and display projection above panel surface. One other basic requirement, and the one that human engineering is primarily concerned with, is that "the Navigation Control Panel must be capable of operation by human beings."



ENVELOPE DIMENSIONS NAVIGATION CONTROL PANEL CONTROL PEDESTAL, L.H. SIDE

from
GRUMMAN AIRCRAFT CORP DRAWING

ANGLES $\pm \frac{1}{2}^\circ$

SCALE: $\frac{1}{2}'' = 1''$

Figure 2 Physical Specifications for W2F-1 Navigation Control Panel

4. Factors affecting design

The Nav-Panel is the operator's means of access to, and control over, the Navigation Computer. The computer is a special purpose machine, designed to perform the necessary computations for navigation of the aircraft. Of necessity, it is complex in nature. A factor to be considered in the Navigation Control Panel design is this complexity. It must be born in mind that a human operator is to communicate with the computer and exercise control over it. The complexity of the computer should not permeate to the operator's controls and displays. The link between the pilot and Navigation Computer is the Nav-Panel. Communication between the man and the machine of the pilot-Nav-Panel subsystem should be as much as possible on the level of the man and not on the level of the computer he is to control. The programming of computers and interpretation of their outputs is normally (best described as) a confusing task. To fulfill its mission in the man-machine subsystem, the Navigation Control Panel must reduce this task to the simplest operator procedures possible.

The location of the Navigation Control Panel in the pilot's compartment is not a human engineering decision. It has been specified by the aircraft manufacturer. The specified location imposes several restraints on the panel design. Figures 3a and 3b are a sketch of the panel and the equipment located in the adjacent area. The aircraft throttle controls are mounted just aft of the panel, restricting access to the lower panel controls. The proximity of the aircraft's throttles necessitates a consideration of the accidental striking of Nav-Panel controls located in the adjacent area.

Due to the space limitations and the requirement of so many display and input functions, it is not only necessary, but desirable, to combine

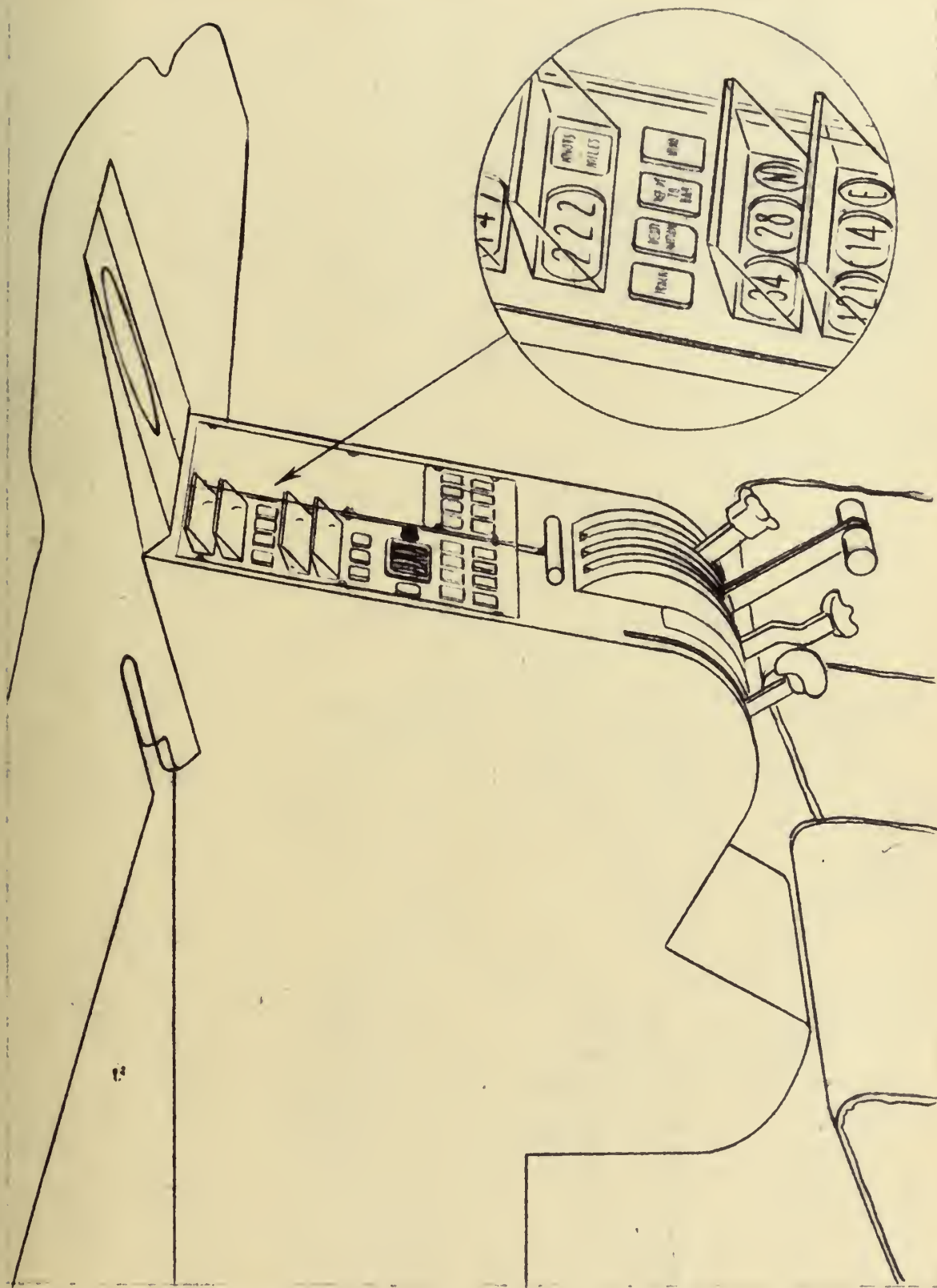


Figure 3a W2F-1 Navigation Control Panel and Adjacent Equipment
(Side View)

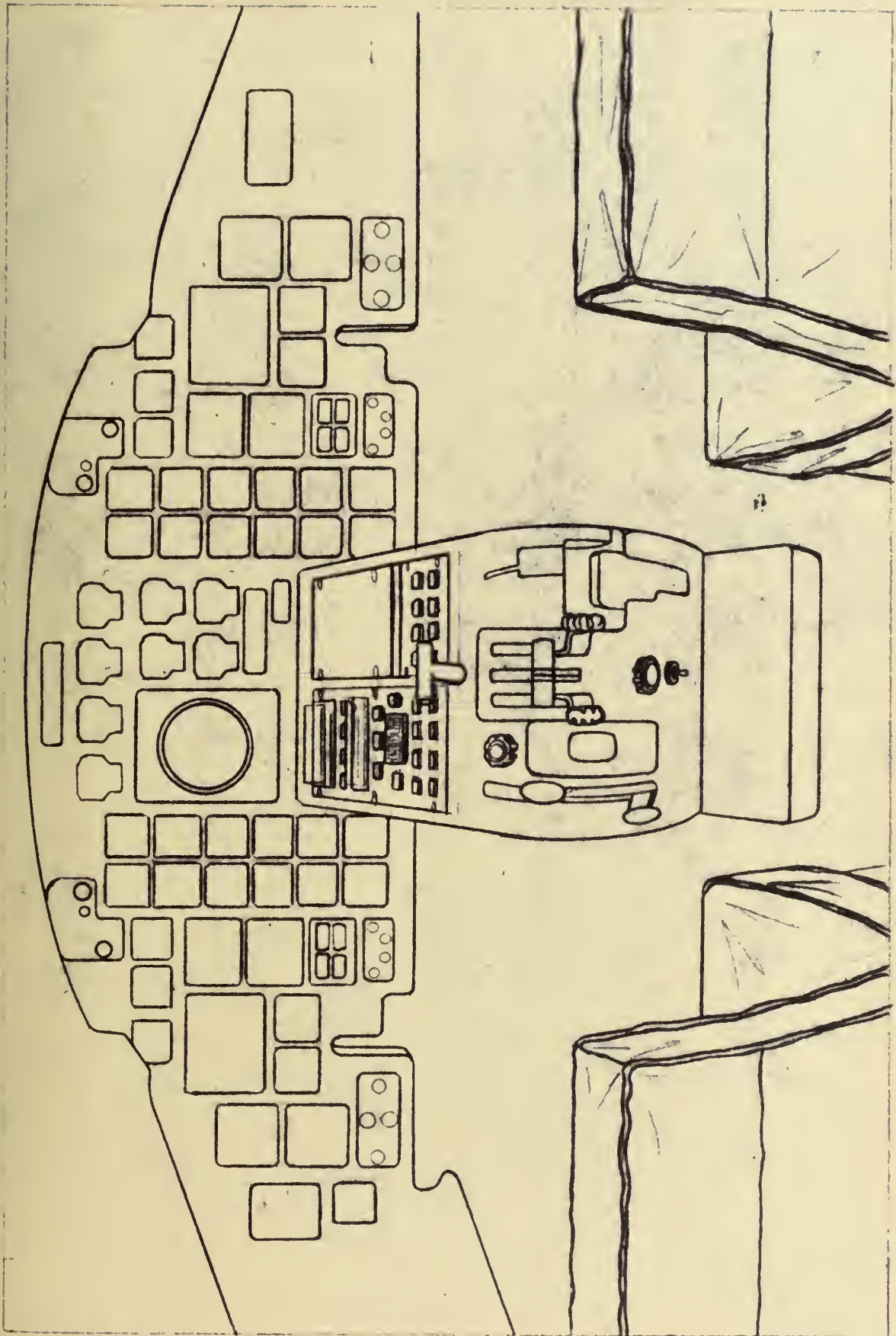


Figure 3b W2F-1 Navigation Control Panel and Adjacent Equipment
(Cockpit View)

the functions of display and input devices, wherever possible and practical. If the quantities were of a single category this combining would be a relatively simple task, in itself. However, such is not the case. There are three distinct types of display and input quantities: (1) bearing and range, (2) course and speed, and (3) latitude and longitude. The human engineering design should permit the combining of the displays and inputs in such a manner as to require a minimum of indicators and controls and still preserve distinction between the different categories.

Being an airborne piece of equipment, weight and size are strong factors affecting the selection of controls, indicators, and their associated circuit components. In conjunction with the airborne considerations there is the problem of illumination. The Nav-Panel controls must be visible for pilot use when flying in excess of 30,000 feet in bright sunlight and when poised for take-off on a blacked-out carrier deck. These requirements impose a severe demand on the display equipment and its illumination.

Other restrictions on the human engineering design of the Navigation Control Panel are the electronic and logic circuits of the computer. The computer circuits have been developed at considerable cost in time and money. The design of the Nav-Panel should be such as to make full use of existing logic and control circuits. While this restriction limits the panel design to some extent, it is justified as a "good engineering practice."

5. Analysis of Prototype Navigation Control Panel No. 1

The analysis of the original design, Prototype Navigation Control Panel No. 1 was performed in three steps. First, a TOPC was constructed using the Functional Description as reference (see Appendix A). Then, with the aid of the TOPC, link analysis diagrams were made. The third step was to complete the Human Engineering Check List. Completion of these three steps formed the basis for the understanding of the Navigation Control Panel operation in its present form.

5.1 Tentative Operational Procedures Chart (TOPC)

To produce the TOPC, it was necessary to first study the Functional Description, which is a complete description of the operation of each control and display item on the Nav-Panel. The next step was to construct the first two columns of the TOPC using the functional description and the required display and data entry functions of the Nav-Panel. With this partially completed TOPC, the electronic and logic designers were consulted and their circuits studied. The results of this investigation permitted the completion of the 3rd and 5th columns of the TOPC. Based on the analyses of the first two columns of the TOPC (task analyses), column 4 (see Appendix C) was then filled in completing the TOPC.

In the course of the above investigations, several interesting facts were revealed. It was discovered that the bearing information was being displayed as degrees magnetic, whereas the specifications called for degrees true. Also original estimates of readout operations from the computer were made as indicating a maximum time lapse of five seconds. This was excessive, and a reappraisal of the display circuit action times was made. The study disclosed that the actual readout

time would not exceed five tenths of a second.

At the time this study was taking place, the program for the Digital Display Programmer, a rotating drum magnetic memory device, was still in a development state. The desirability of producing a displayed readout to the operator as quickly as possible in response to an operator function aided in determining the position of data storage in the programmer. All displayed quantities consist of two computer words (bearing and range, latitude and longitude, bearing and speed). If these words are stored adjacent to each other on the rotating drum there is the possibility of a complete drum revolution prior to any display action. However, if the words are stored on opposite sides of the drum, the maximum time for display of at least one item of the requested information is reduced by one half. It is desirable that an operator receive, as soon as possible, a response when he activates a control (operator feedback); therefore, the words will be stored on opposite sides of the magnetic drum.¹

TOPC Evaluation

A study of the completed TOPC (pp 32-59) for the Navigation Control Panel prototype design leads to the following "desirable" and "undesirable" conclusions:

Desirable

- a. The design will perform all required display and data entry functions.
- b. All operator display functions are simple push button tasks, with operator feedback provided for every push button action.

¹This is an excellent example of how the TOPC, human engineering analysis, can assist the electronic engineering design phases of man-machine systems towards the perfection of the man-machine relationship.

c. No machine times are excessive, i.e., requiring the operator to wait in excess of five seconds.

d. Correction, or data entry, of only part of a displayed quantity is readily effected.

Undesirable

a. Data entry functions are performed in two discrete operations when entering a complete new set of information (latitude and longitude, bearing and speed, or bearing and range).

b. The actuation of a display push button places the associated data entry push buttons in a "live" condition, i.e. they are enabled.

c. Selection of latitude designation, N or S, and longitude designation, E or W, is coincident with the entering operation for these quantities.

d. No "long term" storage of an entered (or to be entered) quantity is possible since the data entry counter wheels must be repositioned to enter the second half of the quantity, not a specification item, but desirable.

There are also conclusions to be drawn from the TOPC that can be placed in an "observed" category. These conclusions can not be classed as desirable or undesirable, but are observations derived from the TOPC study. They are:

Observations

a. For all normal and expected modes of operation the display of two quantities, i.e. a bearing-range and a latitude-longitude, simultaneously is not required.

PROTOTYPE NO. 1 -- TOPC

TABLE OF CONTENTS

OPERATIONAL PROCEDURE	STEP
Wind direction and speed display	1.0
Barrier reference point to barrier center bearing and range display	2.0
Destination bearing and range display	3.0
Track angle and ground speed display	4.0
Barrier reference point latitude and longitude display	5.0
Destination latitude and longitude display	6.0
Present position latitude and longitude display	7.0
Destination latitude and longitude data entry	8.0
Present position latitude and longitude data entry	9.0
Barrier reference point latitude and longitude data entry	10.0
Barrier reference point to barrier center bearing and range data entry	11.0
Wind direction and speed data entry	12.0
Nixie tube brightness adjustment	13.0
Light test	14.0

1.0	Display wind direction and speed.				
1.1	Presses WIND push button.	WIND button lights.	The Nav-Panel interlock circuit acts to extinguish TRACK, upper DESTINATION, or REF PT TO BAR push button if illuminated. WIND illuminate relay holding circuit is energized, closing relay.	M8	2-13 ms.
		KNOTS portion of KNOTS-MILES indicator lights. 1st and 2nd row nixies change indicating 3 numbers each.	KNOTS illuminate relay holding circuit is energized, closing relay. Closing WIND push button circuit sends the "display wind data" signal through an input buffer to the Identification and Selection Matrix. The matrix identifies the input wind display signal, and sends outputs to the Digital Display Programmer requesting the display of wind data. The programmer obtains coincidence with the wind direction and wind speed memory storage of the Navigation Computer, reads out this data in binary form and sends it to the binary-to-decimal converter. The output of the converter is sent to the Nixie Tube Grid Control circuit which applies voltages to the grids of the 1st and 2nd row of nixie tubes corresponding to the wind direction and speed stored in the computer memory.		2-13 ms.
			See Notes 1 and 2.		.25-33 sec.

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIMES
1.2 Reads wind direction (3 numbers displayed in 1st row nixies) and wind speed (3 numbers displayed in 2nd row nixies).			P3, C3	
2.3 Presses WIND push button.	WIND button light extinguishes.	WIND push button illumination relay holding circuit is opened.	M3	2-13 ms.
	KNOTS portion of KNOTS-MILES indicator extinguishes.	KNOTS indicator illumination relay holding circuit is opened.		2-13 ms.
	1st and 2nd row nixies are extinguished.	The "display wind data" signal to the input buffer is terminated. The output of the Identification and Selection Matrix is terminated. The output of the Digital Display Programmer to the binary-to-decimal converter is terminated and no signal is sent to the Nixie Tube Grid Control which causes the nixie tubes to be extinguished.		23.5 ms.-.33 sec.
2.0 Display bearing and range from barrier reference point to barrier center.				
2.1 Presses REF PT TO BAR push button.	REF PT TO BAR button lights.	Nav-Panel interlock circuit acts to extinguish TRACK, upper DESTINATION or WIND push button if illuminated. REF PT TO BAR illumination relay holding circuit is energized, closing the relay.	M8	2-13 ms.
	MILES portion of KNOTS-MILES indicator lights.	MILES illumination relay holding circuit is energized, closing the relay.		2-13 ms.

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIMES
	1st and 2nd row nixies change to indicate 3 figures each.	Closing REF PT TO BAR push button circuit sends the "display REF PT TO BAR data" signal through an input buffer to the Identification and Selection Matrix. The matrix identifies the input signal and sends outputs to the Digital Display Programmer requesting the display of reference point to barrier range and bearing. The programmer obtains coincidence with the reference point to barrier range and bearing memory storage of the Navigation Computer and reads out this information in binary form. It is sent to a binary-to-decimal converter. The output of the converter goes to the Nixie Tube Grid Control circuit which applies voltages to the grids of the 1st and 2nd row of nixie tubes. The grids energized correspond to the reference point to barrier data stored in the computer memory. See Notes 1 and 2.		.25-.33 sec.
2.2 Observes bearing (1st row nixies) and range (2nd row nixies) from barrier reference point to barrier center.			P3, C3	
2.3 Presses REF PT TO BAR push button.	REF PT TO BAR button light extinguishes. MILES portion of KNOTS-MILES indicator extinguishes.	REF PT TO BAR illumination relay holding circuit is opened. MILES indicator illumination relay holding circuit is opened.	M3	2-13 ms. 2-13 ms.

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROBLEMS	PERFORMANCE TIPS
3.2 Reads destination bearing (3 numbers displayed in 1st row nixies) and range (3 numbers displayed in 2nd row nixies).		converter is sent to the Nixie Tube Grid Control circuit which applies voltages to the grids of the 1st and 2nd row of nixie tubes corresponding to the destination range and bearing stored in the computer memory. See Notes 1 and 2.		.25-.33 sec.
3.3 Presses upper DESTINATION push button.	Upper DESTINATION button light extinguishes. MILES portion of KNOTS-MILES indicator extinguishes. 1st and 2nd row nixies are extinguished.	Upper DESTINATION push button illumination relay holding circuit is opened. MILES indicator illumination relay holding circuit is opened. The "display destination range and bearing data" signal to the input buffer is terminated. The output of the Identification and Selection Matrix is terminated. The output of the Digital Display Programmer to the binary-to-decimal converter is terminated and a signal sent to the Nixie Tube Grid Control to cause the nixie tubes to be extinguished.	NE	2-13 sec. 2-13 ms.
4.0 Display track angle and ground speed.				23.5 ms.-.33 sec.
4.1 Presses TRACK push button.	TRACK button lights.	Nav-Panel interlock circuit acts to extinguish upper DESTINATION, REF PT TO BAR, or WIND push button if	NS	

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIMES
	<p>KNOTS portion of KNOTS-MILES indicator lights.</p> <p>1st and 2nd row nixies change to indicate 3 numbers each.</p>	<p>illuminated.</p> <p>TRACK illumination relay holding circuit is energized, closing relay.</p> <p>KNOTS illumination relay holding circuit is energized, closing relay.</p> <p>Closing TRACK push button circuit sends "display track data" signal through an input buffer to the Identification and Selection Matrix. The matrix identifies the input track display signal, and sends outputs to the Digital Display Programmer requesting the display of track angle and ground speed. The programmer obtains coincidence with the track angle and ground speed memory storage of the Navigation-Computer, reads out the requested information in binary form and sends it to the binary-to-decimal converter.</p> <p>The output of the converter operates the Nixie Tube Grid Control circuit which applies voltages to the grids of the 1st and 2nd row of nixie tubes corresponding to the track angle and ground speed stored in the computer memory.</p> <p>See Notes 1 and 2.</p>		<p>2-13 ms.</p> <p>2-13 ms.</p>
4.2	<p>Observes W2F-1's track angle as 3 numbers displayed by 1st row nixies and ground speed as 3 numbers displayed by 2nd row nixies followed by word KNOTS.</p>		F3, C3	

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIME
4.3	Pushes TRACK push button.	<p>TRACK button extinguishes.</p> <p>KNOTS portion of KNOTS-MILES indicator extinguishes.</p> <p>1st and 2nd row nixies are extinguished.</p>	<p>TRACK push button illumination holding relay circuit is opened.</p> <p>KNOTS indicator illumination relay holding circuit is opened.</p> <p>The "display track data" signal to the input buffer is terminated. The output of the Identification and Selection Matrix is terminated. The output of the Digital Display Programmer to the binary-to-decimal converter is terminated and no signal is sent to the Nixie Tube Grid Control circuit which causes the nixie tubes to be extinguished.</p>	<p>2-13 ms.</p> <p>2-13 ms.</p>
5.0	Display barrier reference point latitude and longitude.			23-5 ms. - 15 sec.
5.1	Presses REF PT push button.	<p>REF PT button lights.</p> <p>3rd row nixies change to indicate 4 numbers followed by a letter (N or S) and 4th row nixies change to indicate 5 numbers followed by a letter (E or W).</p>	<p>Nav-Panel interlock circuit acts to extinguish POSIT or lower DESTINATION push button if illuminated.</p> <p>REF PT illumination relay holding circuit is energized, closing relay.</p> <p>Closing REF PT push button circuit sends the "display reference point data" signal through an input buffer to the Identification and Selection Matrix. The matrix identifies the input display reference point data signal and sends output to the Digital Display Programmer requesting the display of reference point latitude and longitude. The programmer obtains coincidence with the reference point latitude and reference point longitude memory storage of the</p>	2-13 ms.

			Navigation Computer, reads out the requested information in binary form and sends it to the binary-to-decimal converter. The output of the converter operates the Nixie Tube Grid Control which applies voltages to the grids of the 3rd and 4th row nixie tubes corresponding to the reference point latitude and longitude stored in the computer.		25-27.3 sec.
			See Notes 1 and 2.		
4.2	Observes reference point latitude as 5 numbers followed by a letter displayed on 3rd row nixies and longitude as 6 numbers followed by a letter displayed by 4th row nixies.			REF PT push button illumination relay holding circuit is opened.	2-1 sec.
5.3	Pushes REF PT push button.	REF PT button extinguishes. 3rd and 4th row nixies extinguish.	The "display reference point data" signal to the input buffer is terminated. The output of the Identification and Selection Matrix is terminated. The output of the Digital Display Programmer to the binary-to-decimal converter is terminated and no signal is sent to the Nixie Tube Grid Control circuit which causes the nixie tubes to be extinguished.		23.5 ms.-.33 sec

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIME
6.0	Display destination latitude and longitude.			
6.1	Presses lower DESTINATION push button.	<p data-bbox="196 286 266 1001">Lower DESTINATION button lights.</p> <p data-bbox="266 286 350 1001">Lower DESTINATION illumination relay holding circuit is energized, closing relay.</p> <p data-bbox="350 286 616 1001">Closing lower DESTINATION push button circuit sends the "display destination latitude and longitude" signal through an input buffer to the Identification and Selection Matrix. The matrix identifies the input display destination data signal and sends outputs to the Digital Display Programmer requesting the display of destination latitude and longitude. The programmer obtains coincidence with the destination latitude and destination longitude memory storage of the Navigation Computer, reads out the requested information in binary form and sends it to the binary- to-decimal converter. The output of the converter operates the Nixie Tube Grid Control circuit applying voltages to the grids of the 3rd and 4th row nixie tubes corresponding to the destination latitude and longitude stored in the computer.</p> <p data-bbox="616 286 686 1001">See Notes 1 and 2.</p>	MS	2-13 ms.

0.2 - .33 sec.

OPERATOR PROCEDURES AND CRITERIA		NORMAL DISPLAY AND CONTROL		RELATIONAL SPECIFICATIONS		PERFORMANCE TIMES
6.2	Observes destination latitude as 5 numbers followed by a letter displayed by 3rd row nixies and longitude as 6 numbers followed by a letter displayed by 4th row nixies.					23, 03
6.3	Pushes lower DESTINATION push button.	Lower DESTINATION button extinguishes. 3rd and 4th row nixies extinguish.	Lower DESTINATION push button illumination relay holding circuit is opened. The "display destination latitude and longitude" signal to the input buffer is terminated. The output of the Identification and Selector Matrix is terminated. The output of the Digital Display Programmer to the binary-to-decimal converter is terminated and no signal is sent to the Nixie Tube Grid Control circuit which causes the Nixie tubes to be extinguished.			2-11 ms.
7.0	Display present position latitude and longitude.					23, 03, 03
7.1	Presses POSIT push button.	POSIT button lights.	Nav-Panel interlock circuit acts to extinguish REF PT or lower DESTINATION push button if illuminated. POSIT illumination relay holding circuit is energized, closing relay.			2-13

3rd row nixies change to indicate 4 numbers followed by a letter (N or S) and 4th row nixies change to indicate 5 numbers followed by a letter (E or W).

Closing POSIT push button circuit sends the "display position data" signal through an input buffer to the Identification and Selection Matrix. The matrix identifies the input display position data signal and sends outputs to the Digital Display Programmer requesting the display of present position latitude and longitude. The programmer obtains coincidence with the position latitude and position longitude memory storage of the Navigation Computer, reads out the requested information in binary form and sends it to the binary-to-decimal converter. The output of the converter operates the Nixie Tube Grid Control which applies voltages to the grids of the 3rd and 4th row nixie tubes corresponding to the present position latitude and longitude stored in the computer.

See Notes 1 and 2.

7.2 Observes WZF-1's present latitude (3rd row nixies) as 4 numbers (degrees and minutes) followed by a letter (N or S) and longitude (4th row nixies) as 5 numbers (degrees and minutes) followed by a letter (E or W).

P3, C3

.25-.33 sec.

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIME
7.3	Presses POSIT push button.	<p>POSIT button extinguishes.</p> <p>3rd and 4th row nixies are extinguished.</p>	<p>POSIT push button illumination relay holding circuit is opened.</p> <p>The "display position data" signal to the input buffer is terminated. The output of the Identification and Selection Matrix is terminated. The output of the Digital Display Programmer to the binary-to-decimal converter is terminated and no signal is sent to the Nixie Tube Grid Control circuit which causes the nixie tubes to be extinguished.</p>	<p>2-4.3 ms.</p>
8.0	Enter destination latitude and longitude.			23.5 sec. ± 3 sec.
8.1	Presses lower DESTINATION push button.	<p>Lower DESTINATION button lights.</p> <p>3rd row nixies change to indicate 4 numbers followed by a letter (N or S) and 4th row nixies change to indicate 5 numbers followed by a letter (E or W).</p>	See 6.1.	
8.2	Observes latitude (3rd row nixies) and longitude (4th row nixies) of destination now present in the Navigation Computer Memory.			P2

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIMES
9.3 Decides the latitude and longitude of destination is incorrect and to enter new data.			C3	
8.4 Positions the DATA ENTRY counter wheels to display correct destination latitude in degrees (1st wheel set to 0, 2nd and 3rd wheels to degrees) and minutes (4th and 5th wheels).			M8, C3	4-25 sec.
8.5 Presses LAT N (or LAT S) push button.	3rd row nixies change to display 4 figures corresponding to the 2nd, 3rd, 4th and 5th DATA ENTRY counter wheel settings, followed by the letter N (or S if LAT S was pressed).	The Data Entry Counter Wheel Sampling circuit is actuated. The 5 counter wheels are sampled sequentially and signals corresponding to their settings are sent to a decimal-to-binary converter. The output of the converter is entered in the Navigation Computer memory storage as destination latitude. The N (or S) designation of the latitude data is denoted by the sign binary digits of the latitude computer word originated by the LAT N (or LAT S) push button circuit. The computer display procedure of step 6.1 is performed and the 3rd row nixie tube grids are energized corresponding to the latitude that has been entered in the computer memory.	M8	
8.6 Observes display of entered destination latitude in 3rd row nixies.			P3	.25- sec.

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIMES
8.7	Positions the DATA ENTRY counter wheels to display correct destination longitude in degrees (1st, 2nd, and 3rd wheels) and minutes (4th and 5th wheels).		M8	
8.8	Presses LONG E (or LONG W) push button. 4th row nixies change to display 5 figures corresponding to the 5 DATA ENTRY counter wheel settings, followed by the letter E (or W if LONG W was pressed).	The Data Entry Counter Wheel Sampling circuit is actuated. The 5 counter wheels are sampled sequentially and signals corresponding to their settings are sent to a decimal-to-binary converter. The output of the converter is entered in the Navigation Computer memory storage as destination longitude. The E (or W) designation of the longitude data is indicated by the sign binary digits of the longitude computer word originated by the LONG E (or LONG W) push button circuit. The computer display procedure of step 6.1 is performed and the 4th row nixie tube grids are energized corresponding to the longitude that has been entered in the computer memory.	M8	1-10 sec.
8.9	Observes display of entered destination longitude in 4th row nixies.		P3	.25-.5 sec.
8.10	Decides destination latitude and longitude now in the Navigation Computer is correct and entry operation is complete.		C3	

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIME
8.11	Presses lower DESTINATION push button.	Lower DESTINATION button extinguishes. 3rd and 4th row nixies are extinguished.	MS	2-13 ms. 23.5 ms.-.33 sec.
9.0	Enter present position latitude and longitude.			
9.1	Presses POSIT push button.	POSIT button lights. 3rd row nixies change to indicate 4 numbers followed by a letter (N or S) and 4th row nixies change to indicate 5 numbers followed by a letter (E or W).	MS	2-13 ms. .25-.33 sec.
9.2	Observes present position now in the Navigation Computer memory as latitude in degrees and minutes, N or S (3rd row nixies) and longitude in degrees and minutes, E or W (4th row nixies).		P3	
9.3	Decides the latitude and longitude of present position is incorrect and to enter new data.		C3	

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIMES
9.4 Positions DATA ENTRY counter wheels to display correct latitude in degrees (1st wheel set to 0, 2nd and 3rd wheels to degrees) and minutes (4th and 5th wheels).			M8, C3	
9.5 Presses LAT N (or LAT S) push button.	3rd row nixies change to display 4 numbers corresponding to the 2nd, 3rd, 4th and 5th DATA ENTRY counter wheel settings, followed by the letter N (or S if LAT S was pressed).	The Data Entry Counter Wheel Sampling circuit is actuated. The 5 counter wheels are sampled sequentially and signals corresponding to their settings are sent to a decimal-to-binary converter. The output of the converter is entered in the Navigation Computer memory storage as present position latitude. The N (or S) designation of the latitude data is denoted by the sign binary digits of the latitude computer word originated by the LAT N (or LAT S) push button circuit. The computer display procedure of step 7.1 is performed and the 3rd row nixie tube grids are energized corresponding to the latitude that has been entered in the computer memory.	M8	.25-.5 sec.
9.6 Observes display of present position latitude in 3rd row nixie tubes.			P3	

PERFORMANCE T.M.L.	PSYCHOLOGICAL PROCEDURE	RELATIONAL SPECIFICATIONS	NORMAL DISPLAY AND CONTROL	OPERATOR PROCEDURES AND CRITERIA	
P3				<p>9.7 Positions DATA ENTRY counter wheels to display correct position longitude in degrees (1st, 2nd and 3rd wheels) and minutes (4th and 5th wheels).</p> <p>9.8 Presses LONG E (or LONG W) push button.</p>	
P3		<p>The Data Entry Counter Wheel Sampling circuit is actuated. The 5 counter wheels are sampled sequentially and signals corresponding to their settings are sent to a decimal-to-binary converter. The output of the converter is entered in the Navigation Computer memory storage as present position longitude. The E (or W) designation of the longitude data is indicated by the sign binary digits of the longitude computer word originated by the LONG E (or LONG W) push button circuit. The computer display procedure of step 7.1 is performed and the 4th row nixie tube grids are energized corresponding to the longitude that has been entered in the computer memory.</p>	<p>4th row nixies change to display 5 numbers corresponding to the 5 DATA ENTRY counter wheel settings, followed by the letter E (or W if LONG W was pressed).</p>		
P3				<p>9.9 Observes display of entered present position longitude in 4th row nixies.</p>	
C3				<p>9.10 Decides present position latitude and longitude now in the Navigation Computer is correct and entry operation is complete.</p>	

..5-.5 sec.

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIME
9.11	Presses POSIT push button.	POSIT button extinguishes. 3rd and 4th row nixies are extinguished.	M3	2-13 ms.
10.0	Enter barrier reference point latitude and longitude.			23.5 ms.--.33 sec.
10.1	Presses REF PT push button.	REF PT button lights. 3rd row nixies change to indicate 4 numbers followed by a letter (N or S) and 4th row nixies change to indicate 5 numbers followed by a letter (E or W).	M3	2-13 ms.
10.2	Observes latitude (3rd row nixies) and longitude (4th row nixies) of barrier reference point now present in the Nav- igation Computer memory.		P3	.25-.33 sec.
10.3	Decides the latitude and longitude of the barrier reference point is incorrect and to enter new data.		C3	

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIMES
10.4	Positions the DATA ENTRY counter wheels to display correct latitude of barrier reference point in degrees (1st wheel set to 0, 2nd and 3rd wheels to degrees) and minutes (4th and 5th wheels).		MS, C3	4-6 sec.
10.5	Presses LAT N (or LAT S) push button.	3rd row nixies change to display 4 figures corresponding to the 2nd, 3rd, 4th and 5th DATA ENTRY counter wheel settings, followed by the letter N (or S if LAT S was pressed).	MS	
10.6	Observes display of entered barrier reference point latitude in 3rd row nixie tubes.	The Data Entry Counter Wheel Sampling circuit is actuated. The 5 counter wheels are sampled sequentially and signals corresponding to their settings are sent to a decimal-to-binary converter. The output of the converter is entered in the Navigation Computer memory storage as barrier reference point latitude. The N (or S) designation of the latitude data is denoted by the sign binary digits of the latitude computer word originated by the LAT N (or LAT S) push button circuit. The computer display procedure of step 5.1 is performed and the 3rd row nixie tube grids are energized corresponding to the latitude that has been entered in the computer memory.	P3	2-4 sec.

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIMES
10.7	Positions the DATA ENTRY counter wheels to display correct barrier reference point longitude in degrees (1st, 2nd, and 3rd wheels) and minutes (4th and 5th wheels).	4th row nixie tubes change to display 5 numbers corresponding to the 5 DATA ENTRY counter wheel settings, followed by the letter E (or W if LONG W was pressed).	M8	4-10 sec.
10.8	Presses LONG E (or LONG W) push button.	4th row nixie tubes change to display 5 numbers corresponding to the 5 DATA ENTRY counter wheel settings, followed by the letter E (or W if LONG W was pressed).	M3	4-10 sec.
10.9	Observes display of entered barrier reference point longitude in 4th row nixie tubes.	The Data Entry Counter Wheel Sampling circuit is actuated. The 5 counter wheels are sampled sequentially and signals corresponding to their settings are sent to a decimal-to-binary converter. The output of the converter is entered in the Navigation Computer memory storage as barrier reference point longitude. The E (or W) designation of the longitude data is indicated by the sign binary digits of the longitude computer word originated by the LONG E (or LONG W) push button circuit. The computer display procedure of step 5.1 is performed and the 4th row nixie tube grids are energized corresponding to the longitude that has been entered in the computer memory.	F3	4-10 sec.

OPERATOR PROCEDURES AND CRITERIA		NORMAL DISPLAY AND CONTROL		RELATIONAL SPECIFICATIONS		PSYCHOLOGICAL PROCESSES	PERFORMANCE TIME
10.10	Decides barrier reference point latitude and longitude now in the Navigation Computer is correct and entry operation is complete.					C3	
10.11	Presses REF PT push button.	REF PT button is extinguished.	See 5.3.			M9	2-13 ms. ^m
11.0	Enter barrier reference point to barrier center bearing and range.	3rd and 4th row nixie tubes are extinguished.					23.5 ms. - .33 sec
11.1	Presses REF PT TO BAR push button.	REF PT TO BAR button lights. MILES portion of KNOTS-MILES indicator lights. 1st and 2nd row nixies change to display 3 numbers each.	See 2.1.			M8	2-13 ms. 2-13 ms. .25-.33 sec.
11.2	Observes bearing (1st row nixies) and range (2nd row nixies followed by MILES indicator) from barrier reference point to barrier center that is now in Navigation Computer.					P3	

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIMES
11.3	Decides the bearing and range from barrier reference point to barrier center is incorrect and to enter new data.		C3	
11.4	Positions the 1st, 2nd, and 3rd DATA ENTRY counter wheels to display correct bearing in degrees from barrier reference point to barrier center.		M5, C3	
11.5	Presses <u>REQ</u> REF PT TO BAR push button.	1st row nixies change to display 3 numbers corresponding to the 1st, 2nd, and 3rd DATA ENTRY counter wheel settings.	M3	The Data Entry Counter Wheel Sampling circuit is actuated. The 1st, 2nd and 3rd counter wheels are sampled sequentially and signals corresponding to their settings are sent to a decimal-to-binary converter. The output of the converter is entered in the Navigation Computer memory storage as barrier reference point to barrier center bearing. The computer display procedure of step 2.1 is performed and the 1st row nixie tube grids are energized corresponding to the barrier reference point to barrier center bearing that has been entered in the computer memory.
11.6	Observes display of entered barrier reference point to barrier center bearing by 1st row nixie tubes.		P3	.25-.5 sec.

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE
11.7	Positions the 1st, 2nd and 3rd DATA ENTRY counter wheels to display correct barrier reference point to barrier center range (in miles).		M3	4-C FIC.
11.8	Presses <u>RANGE REF</u> PT TO BAR push button.	2nd row nixies change to display 3 numbers corresponding to the 1st, 2nd and 3rd DATA ENTRY counter wheel settings.	M3	4-C FIC.
11.9	Observes display of entered barrier reference point to barrier center range in 2nd row nixie tubes.	The Data Entry Counter Wheel Sampling circuit is actuated. The 1st, 2nd and 3rd counter wheels are sampled sequentially and signals corresponding to their settings are sent to a decimal-to-binary converter. The output of the converter is entered in the Navigation Computer memory storage as barrier reference point to barrier center range. The computer display procedure of step 2.1 is performed and the 2nd row nixie tube girds are energized corresponding to the barrier reference point to barrier center range that has been entered in the computer memory.	P3	4-C FIC.
11.10	Decides barrier reference point to barrier center bearing and range now in the Navigation Computer is correct and entry operation is complete.		C3	

OPERATOR PROCEDURES AND CRITERIA		NORMAL DISPLAY AND CONTROL		RELATIONAL SPECIFICATIONS		PSYCHOLOGICAL PROCEDURES	PERFORMANCE TIMES
11.1.1	Presses REF PT TO BAR push button.	REF PT TO BAR button is extinguished. MILES portion of KNOTS- MILES indicator extinguishes. 1st and 2nd row nixies are extinguished.	See 2.3.			M ⁶	2-13 ms. 2-13 ms. 23.5 ms.-.33
12.0	Enter wind direction and speed.						
12.1	Presses WIND push button.	WIND button lights. KNOTS portion of KNOTS- MILES indicator lights. 1st and 2nd row nixies change to display 3 numbers each.	See 1.1.			M ⁸	2-13 ms. 2-13 ms. .25-.33 sec.
12.2	Observes wind direction in degrees as displayed by 1st row nixies, and wind speed in knots as displayed by 2nd row nixies.					P ³	
12.3	Decides the wind direction and speed data now in the computer is incorrect and to enter new data.					C ⁵	
12.4	Positions the 1st, 2nd, and 3rd DATA ENTRY counter wheels to display correct wind dir- ection in degrees.					M ⁴ , C ³	4-6 sec.

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIMES
12.5 Presses WIND DIR push button.	.1st row nixies change to display 3 numbers corresponding to the 1st, 2nd, and 3rd DATA ENTRY counter wheel settings.	The Data Entry Counter Wheel Sampling circuit is actuated. The 1st, 2nd, and 3rd counter wheels are sampled sequentially and signals corresponding to their settings are sent to a decimal-to-binary converter. The output of the converter is entered in the Navigation Computer memory storage as wind direction. The computer display procedure of step 1.1 is performed and the 1st row nixie tube grids are energized corresponding to the wind direction that has been entered in the computer memory.	M8	.25-.5 sec.
12.6 Observes display of entered wind direction by 1st row nixie tubes.			P3	
12.7 Positions the 1st, 2nd and 3rd DATA ENTRY counter wheels to display correct wind speed.			M9	4-6 sec.
12.8 Presses WIND SPEED push button.	2nd row nixies change to display 3 numbers corres- ponding to 1st, 2nd, and 3rd DATA ENTRY counter wheel settings.	The Data Entry Counter Wheel Sampling circuit is actuated. The 1st, 2nd, and 3rd counter wheels are sampled sequentially and signals corresponding to their settings are sent to a decimal-to-binary converter. The output of the converter is entered in the Navigation Computer memory storage as wind speed. The computer display procedure of step 1.1 is performed and the 2nd row nixie tube grids are energized corresponding to the wind speed that has been entered in the computer memory.	P3	.25-.5 sec.

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIMES
12.9	Observes display of entered wind speed by 2nd row nixie tubes.		P3	
12.10	Decides wind direction and speed now in the Navigation Computer is correct and entry operation is complete.		C3	
12.11	Presses WIND push button.	WIND button extinguishes.	M8	2-13 ms.
		KNOTS portion of KNOTS-MILES indicator extinguishes.		2-13 ms.
		1st and 2nd row nixies are extinguished.		23.5 ms.-.33 sec.
13.0	Adjustment of nixie tube brightness.			
13.1	Observes nixie tubes and decides the brightness is too low (or too high).		P3, C3	
13.2	Turns COUNTER BRIGHTNESS knob clockwise (or counter- clockwise if too high), observing nixie tube bright- ness until desired level is reached.	Nixie tubes that are illuminated increase (or decrease) in bright- ness.		Changing the COUNTER BRIGHTNESS control causes the Nixie Illumination Control Circuit to change the frequency of voltage application to the grids of the nixie tubes.
14.0	Light test.			
14.1	Decides to perform a check on indicator and push button lights.		C3	

OPERATOR PROCEDURES AND CRITERIA			NORMAL DISPLAY AND CONTROL		RELATIONAL SPECIFICATIONS		PSYCHOLOGICAL PROCESSES	PERFORMANCE TIMES
11.2	Presses LIGHT TEST push button and holds it depressed.	All functioning indicator and push button lights illuminate.	Nav-Panel interlock circuit acts to apply "bright illuminate" voltage to all indicators and push buttons.	M3				2-13 ms.
11.3	Observes illumination of all functioning light bulbs by scanning the panel for non-lighted indicators and push buttons.			P3, Q4				
11.4	Releases LIGHT TEST push button.	Indicator and push-button lights are extinguished except for those that were illuminated prior to pressing of LIGHT TEST button.	Nav-Panel interlock circuit acts to remove "bright illuminate" voltage from indicators and push buttons except for those energized by previous push button action that is still in effect.	M3				2-13 ms.
			Note 1: Either row of nixie tubes may light first, since the display operation is performed sequentially and the information is stored in separate Navigation Computer memory storage. Note 2: The above readout procedure is repeated approximately every .3 seconds; as new data is inserted in the memory storage by the computer it is processed and different grids of the nixie tubes are energized corresponding to the new data.					

5.2 Link Analysis

Using the completed TOPC as a guide, a link analysis for the five data entry procedures was performed. Figures 4 through 8 are the link analysis diagrams for the five data entry functions. Individual operator steps are indicated by the circled numbers. The numbers indicate the sequence of the data entry operation.

Link Analysis Evaluation

From a study of the five link analysis diagrams the following conclusions are drawn:

a. A disrupted flow of operator procedures is evident in every case.

For example, consider Figure 4, destination latitude and longitude data entry. After push button step 7 is performed, the operator must return to the data entry counter wheels and reposition them (steps 8 through 12) and then return to a push button operation, step 13. Considering the data entry operation is push button and counter wheel groups, the destination latitude and longitude entry is performed as:

Push button operation.....a select function

Counter wheel manipulation.....a positioning function

Push button operation.....an enter function

Counter wheel manipulation.....a positioning function

Push button operation.....an enter function

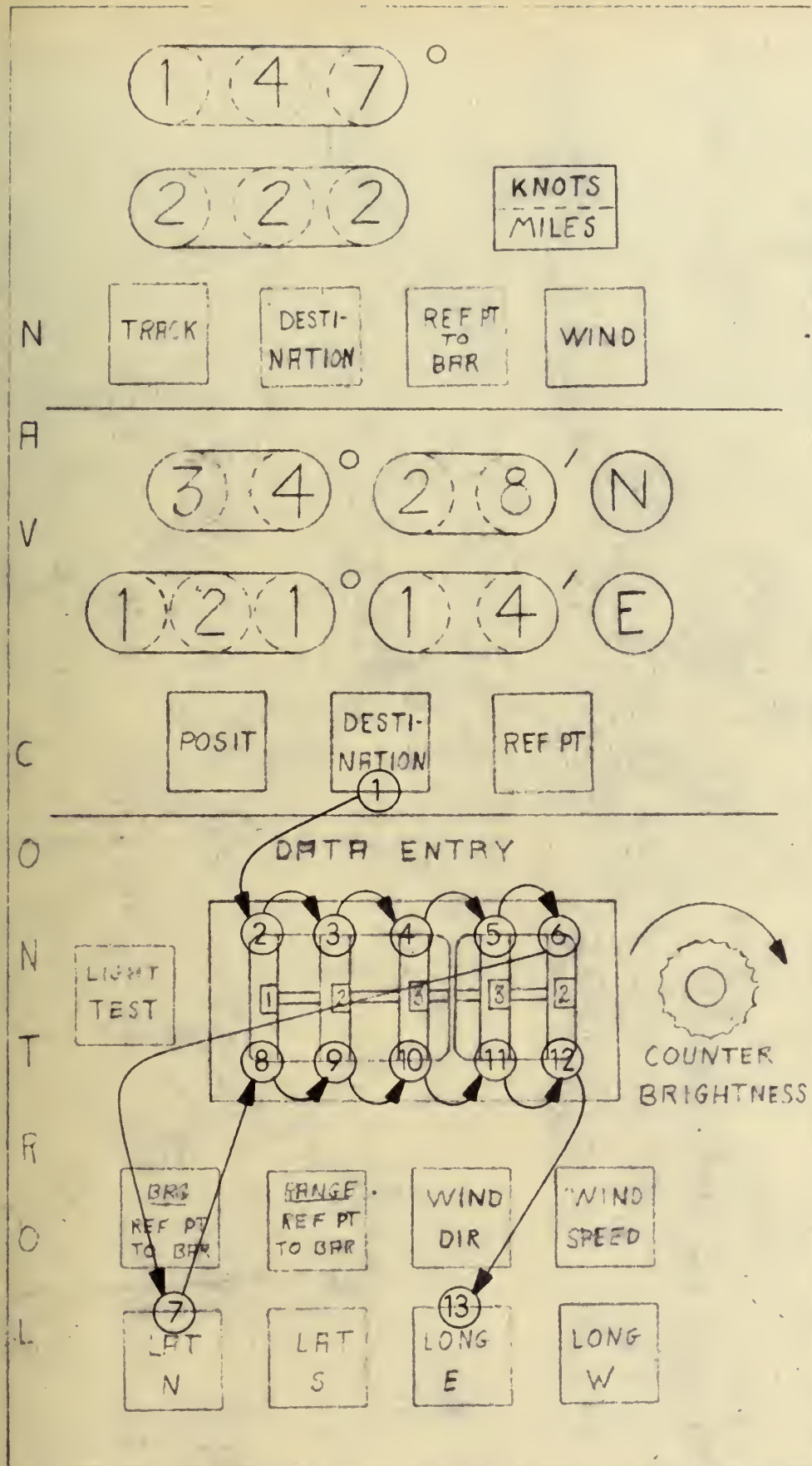
It is desirable (from an operator performance point of view) to perform as many similar operations at one time as possible. The above procedure requires the operator to recount his actions

four times (from push button operation to counter wheel rotation and vice versa).

b. From the diagrams the lack of left-to-right and top-to-bottom sequence of actions is readily apparent.

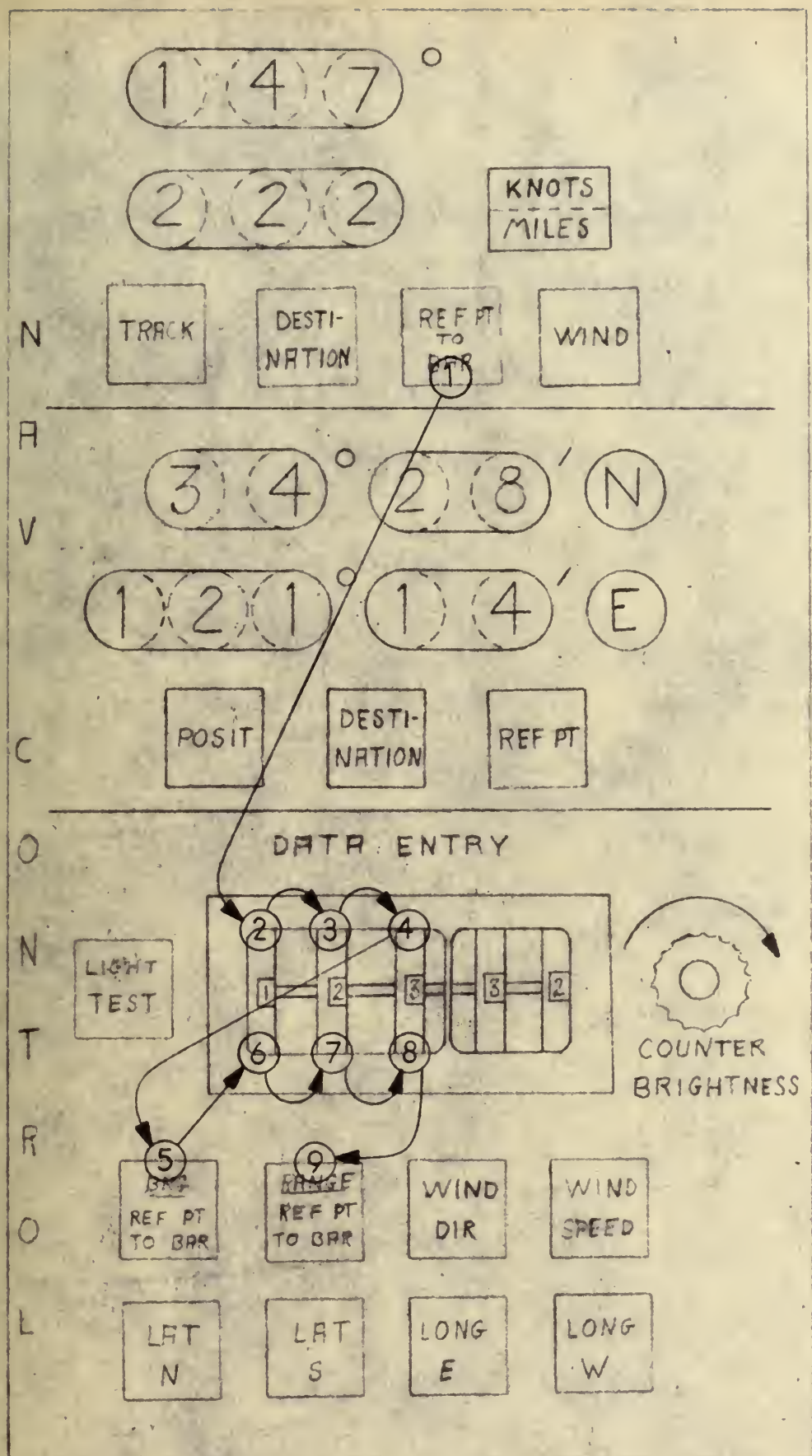
c. A lack of control grouping for data entry operation is in evidence.

d. From Figures 4, 6, and 7 it is revealed that the operator is required to pass over four data entry buttons that may be in a "live" condition. That is, depending on the state of the REF PT TO BAR and WIND push button, two of their associated data entry buttons could be in a condition wherein they would change the reference point to barrier or wind information in the computer if accidentally struck.



PROTOTYPE
DESIGN

Figure 4 Link Analysis - Enter destination latitude and longitude.



PROTOTYPE
DESIGN

Figure 5 Link Analysis - Enter barrier reference point to barrier center bearing and range.

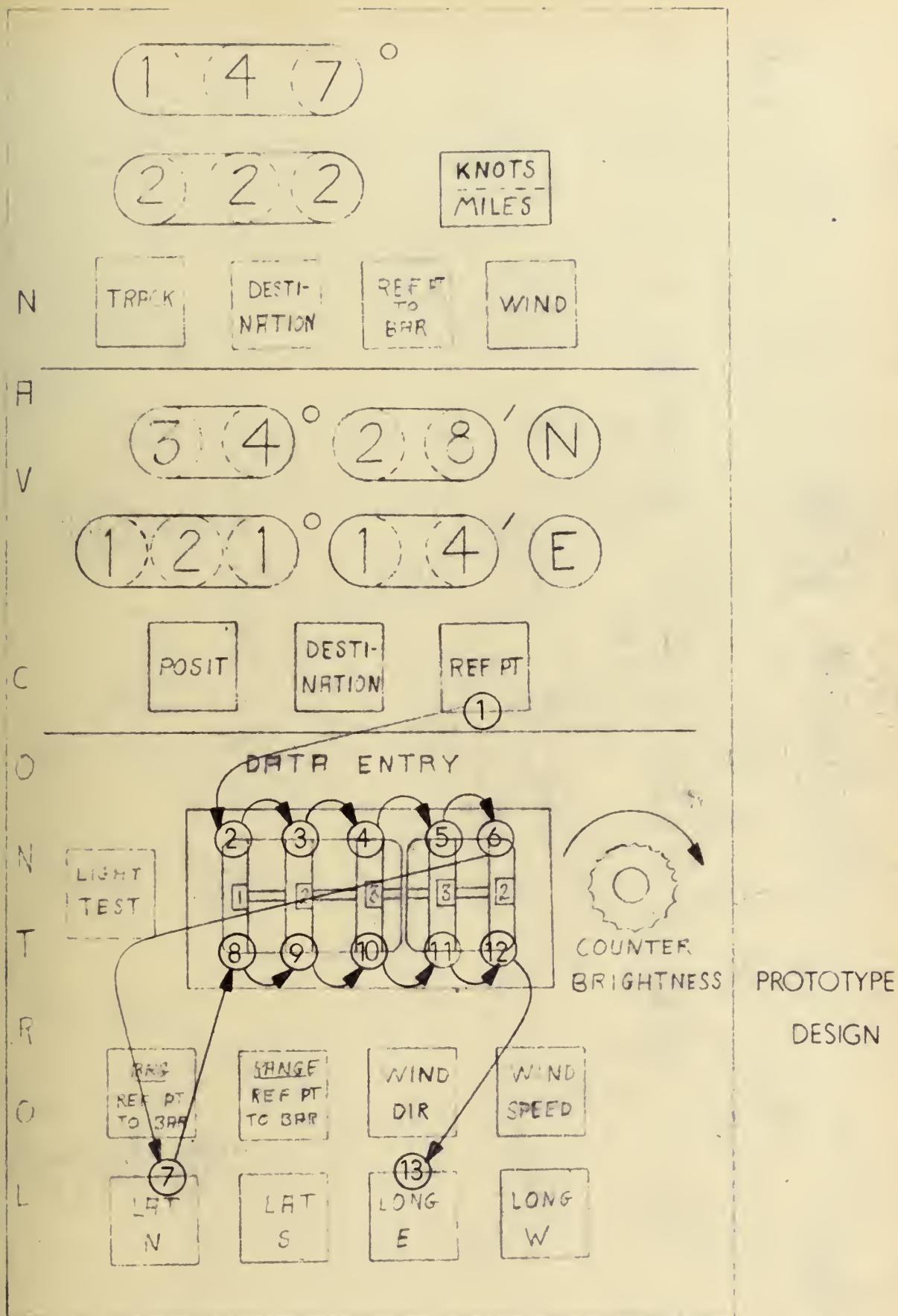
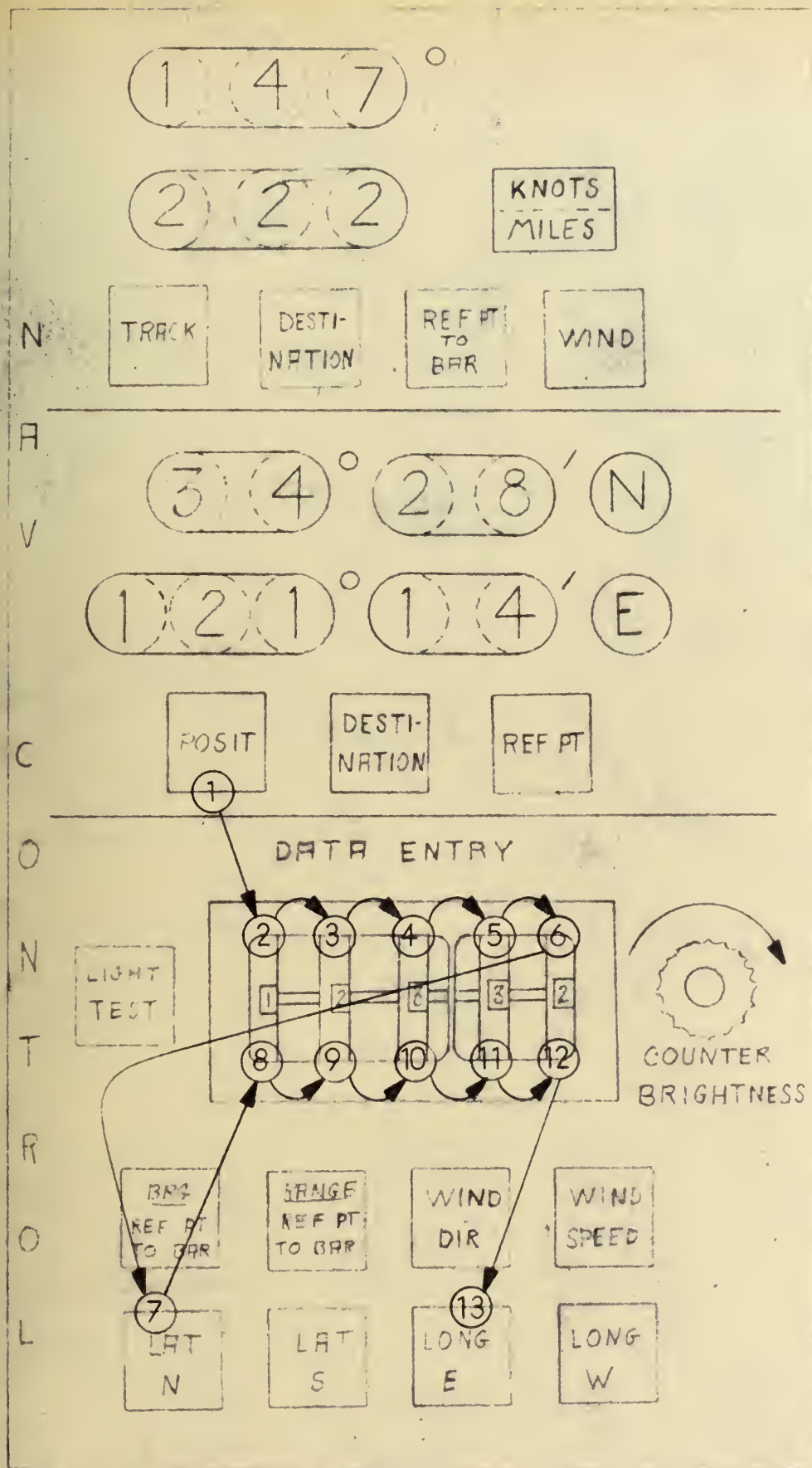


Figure 6 Link Analysis - Enter barrier reference point latitude and longitude.



PROTOTYPE
DESIGN

Figure 7 Link Analysis - Enter present position latitude and longitude.

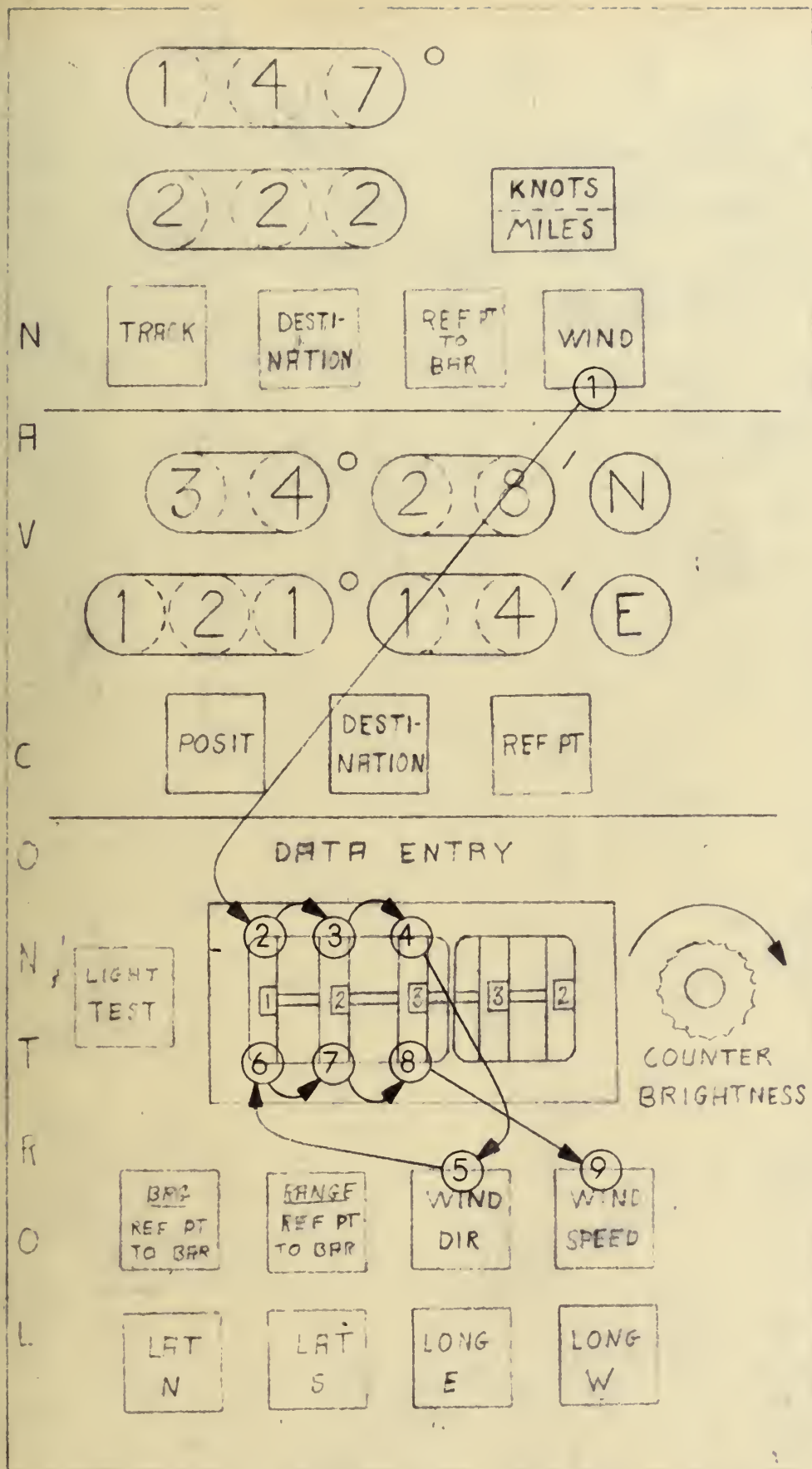


Figure 8 Link Analysis - Enter wind direction and speed.

5.3 Human Engineering Check List Analysis

The third step in the analysis of the original design was to complete the human engineering check list. The check list was derived by the writer from a much larger one¹ developed specifically for analysis use. It consists of definite statements designed to produce an appraisal of the Nav-Panel design based on known human engineering criteria and control and indicator design requirements.

The use of a check list in an analysis study must be approached with caution. By its very nature a check list can not provide degrees of acceptance or satisfactory conditions. Each item requires a "yes" or "no" answer. Most of the check list items are such that this type of answering provides a precise analysis of the condition questioned. There are some items, however, that require an opinionated "yes" or "no." These questions must be approached with the state of mind, "Can the condition described be improved?" The check list has been used to provide a means of focusing attention on specific items of design and questioning their adequacy.

Each statement is answered either "yes" or "no" (or not applicable, NA).

Human Engineering Check List Evaluation

The results of the check list analysis of the prototype Nav-Panel design are summarized in the following statements:

- a. Critical push buttons (data entry) are not recessed or provided

¹ The 192 items of the check list were extracted from an unpublished list of over 300 items compiled by the Litton Human Factors Group. The check list items are derived from many sources: textbooks on human engineering, research papers, and government handbooks and specifications. Many of the items are based on studies conducted to determine the best means of producing a desired stimulus in the majority of intended operators.

with safety guards, they do not provide protection against accidental manipulation. Items 2 and 32.

b. The use of only one control to set up a given condition or perform a given function is not employed in all instances. There are eight data entry push buttons, including two for latitude and two for longitude functions. The data entry controls should be reduced in number. Item 16.

c. Controls requiring "long" periods of manipulation and small adjustments are not mounted so that the hand has a resting place. Operation of the data entry counter wheels should be improved, if at all possible; the counter wheels are surrounded by eight push buttons and a control knob. Item 23.

d. Information is not presented to the operator so that the need for correlation is avoided. The operator must correlate the displayed figures with a lighted push button for every display function. Item 33.d.

e. Not all necessary operator information is shown. All inputs into the system by the operator are not indicated. The data entry counter wheels are not labeled to indicate which wheels are used for the various types of data entry quantities. Items 45, 118, and 151.

f. An improvement in equipment setup should be made. There are eight data entry push buttons, some of these should be combined in an attempt to reduce the number of buttons used for this function. A more positive indication of how data entry operations are executed should be provided. Item 56. (Also see (b) above).

g. Controls are not laid out according to their expected or required order of operation following a left-to-right, top-to-bottom ordering. This statement is made clear by referring to the link analysis diagrams, Figures 4 thru 8. Successive control movements are not interrelated so that one movement passes easily into the next. An improvement should be made in the sequencing of the data entry functional steps. Items 81 and 105.

h. The grouping of the push buttons does not indicate which ones are used for data entry and display, and which ones are used only for display functions. Items 82, 85, 118, 152, and 182.

i. Data entry push button control separation should be improved to prevent accidental manipulation of the wrong control. There are six of the eight data entry push buttons which may be placed in a "live" condition at one time. Item 98.

j. Frequently used controls are not mounted forward, between elbow and shoulder height, off-center in line with arm plane, and near working position. (While this is a deficient item, it cannot be corrected due to the specified location of the Nav-Panel.) Item 101.

k. Labeling of the data entry counter wheels does not tell the operator "what to do." Items 145, 148, and 151.

l. The labels on the first row of push buttons cannot be seen when the viewing prisms are in place over the third and fourth row of nixie tubes. Item 177.

m. Marked outline or boxing is not used to relate associated controls for data entry functions. Item 185.

CHECK LIST FOR PROTOTYPE DESIGN

I. Controls

A. Push Buttons

1. Do the push buttons have a click contact?
2. Are critical push buttons recessed or provided with safety guards?
3. Do the push buttons require less than 10 oz. force for momentary pushing?
4. Do the push buttons require a maximum of 25 oz. force for continuous pushing?
5. Do the push buttons use a pushing surface of at least 1/2 inch in diameter?
6. Are push button switches used for one or two discrete positions?

B. Adjustment Knobs

7. Are adjustment knobs that are used for non-critical or course adjustments approximately 1 inch in diameter?
8. Are round knobs used for controls requiring smooth continuous movement?
9. Do adjustment knobs give definite resistance to movements yet can be turned smoothly for short distances?
10. Do adjustment-type knobs use very light torque? (Approximately 2 inch lbs.)
11. Are knobs less than 3/4 inch in depth knurled?
12. Are knobs more than 3/4 inch in depth serrated?
13. Do serrated knobs have evenly spaced serrations and pointed edges?

II. General Considerations

14. Are all of the controls necessary to the operator in performing his task?
15. Are controls that follow in sequence interlocked so that they cannot be activated prematurely?
16. Where possible, is only one control used to set up a given condition or perform a given function?

17. Does a given control produce the same effect under different conditions?
18. Are controls located so that control movements avoid contact with equipment that could cause injury?
19. Are control movements free of obstructions?
20. Are control movements unkindered by clothing or personal equipment?
21. Is malfunctioning of a control obvious to the operator?
22. Are as few control movements as possible used?
23. Are controls requiring long periods of manipulation and small adjustments mounted so that the hand has a resting place?
24. Does the control consistently produce one effect for a given manipulation?
25. Are control actions positive without being sticky or stiff?
26. Are all control functions well within the limits of the physical strength of the population of operators?
27. Is shape coding used on controls that must be identified without visual aid?
28. Do the controls have a positive indication that they have been correctly positioned?
29. Do control movements to the left, counter-clockwise or down produce effects of left, off, or decrease, or negative increase?
30. Do controls appear to fit the job for which they are intended? (If there is little pressure required they should not be big and bulky, and if a lot of pressure or speed is required they should not appear fragile.)
31. Do control movements to the right, clockwise or up produce effects of right, on, or increase, or negative decrease?
32. Do critical controls provide protection against accidental manipulation?

✓	
✓	
	✓
✓	
✓	
✓	
	✓
✓	
✓	
✓	
✓	
N	A
✓	
✓	
✓	
✓	
	✓

III. Information Presentation

A. General Considerations

33. Is information presented to the operator so that the need for the following activities is avoided?
 - a. sorting or assembling information
 - b. making routine calculations on data
 - c. translating or transposing information
 - d. correlating information
 - e. making predictions on the basis of information
34. Are judgments required of the operator kept to a minimum?
35. Is the need for an action by the operator and the specific action required indicated by a display?
36. Do the instruments permit direct interpretation and use of the information presented?
37. Do displays of similar information permit similar interpretation?
38. Is information presented to the operator so that there is only one possible interpretation?
39. Does a given indication have only one meaning?
40. Do the instruments present the required information in the most meaningful form?
41. Is the information presented to a single operator unduplicated except in the following situations?
 - a. where its relationship in the sequencing of operation varies
 - b. where it is required when the operator's attention is focused in different areas
42. Is all the information displayed essential for the operator to complete his task?
43. Is information presented to the operator only if it is required for his use in performing the required operations or tasks?

[illegible]

44.	Is the presentation of unnecessary information avoided?	✓	
45.	Is all necessary information shown?		✓
46.	Does a single indicator display only one kind of information?	✓	
47.	Is all information presented on a single display related?	✓	
48.	Do the operational displays or associated indicators indicate equipment malfunctioning?	✓	
49.	Is non-operation of the equipment indicated?	✓	
50.	Is the need for a correction or change in the system indicated to the operator in sufficient time so that he may prepare to execute the required action?	✓	
51.	Is the warm-up or "ready to go" condition of the equipment indicated?	✓	
52.	Are crucial visual checks identified by attention-getting devices?	✓	
53.	Are changes in display easy to detect?	✓	
54.	Is the displayed information presented without lag behind the function being displayed?	✓	
55.	Is parallax avoided in displays?	✓	
56.	Is equipment easy to set up for operation?		✓
B. Indicator Lights			
57.	Are indicator lights used for presenting just a few discrete conditions such as "ON-OFF" or "GOOD BAD"?	✓	
58.	Do indicator lights used to present a given condition go "on" to indicate that condition?	✓	
59.	Is a light going "off" to indicate a required action avoided?	N	A
60.	Are indicator lights that are not controlled by the operator or are not generally off kept at a minimum?	✓	
61.	Do warning signals remain on until the unfavorable condition is corrected?	N	A

105. Are successive control movements inter-related so that one movement passes easily into the next?

V. Functional & Operational Considerations

106. Is the completion of an automatic sequence indicated when it requires an action on the part of the observer.
107. When the operator must wait for an automatic sequencing to finish, does he have an indication that the sequencing is occurring?
108. When equipment warm-up is required before the operator can start operations, is there an indication when the equipment is warmed up?
109. When the operator is required to wait more than 10 seconds between indications, is there an indicator light that shows the equipment is working?
110. Is an auditory signal used in place of or in addition to a light, as an attention getting device in a critical situation, except when the operator's field of vision and attention is by necessity focused in the immediate area of the light at all times that the light may come on?
111. In a critical situation, is an auditory signal given when the operator's attention is required when there is an indefinite wait period prior to the operation?
112. Is the setting up of pre-operation conditions indicated so that operations will not begin prematurely?
113. Does the operating procedure for the equipment include a light check?
114. Is the operator free from requirements for making time estimates?
115. Is automatic sequencing used only when no manual operations are required?
116. Are unfavorable conditions corrected or alleviated automatically where feasible?

	✓
✓	
N	A
N	A
N	A
N	A
✓	
✓	
✓	
✓	
✓	
✓	

117. Is the equipment mounted so that vibration of visual displays is minimized?
118. Are all inputs put into the system by the operator indicated?

VI. General Control & Display Considerations

119. Are unique controls and displays used only when they are known to give improved operator performance?
120. Are controls and displays used for the same functions as other equipments of the system the same?
121. Are controls and displays that are standard among other equipments used on this equipment?
122. Are instruments that are functionally similar, structurally and operationally similar?
123. Are the displays and controls the same as those common among other systems?
124. Are the controls and displays of the equipment or system, structural and functionally similar?
125. Is standardization or sameness used on multiple instrument displays?
126. Are uniform controls used for similar purposes?

VII. Work Area Layout

127. Are objects to be viewed at least 13 inches from the operator's eyes?
128. Are glossy surfaces and highly polished metals avoided?
129. Are physical hazards within the work area and movement area of the operator avoided?

VIII. Illumination

130. Are the indicators illuminated so that the ratio of the brightest to dimmest is less than 7 to 1?

✓	
	✓
✓	
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✓	
✓	
✓	
✓	
✓	

131. On important indicator lights is the maximum possible dimming still readily visible?

✓	
---	--

132. Can all indicator lights be seen when maximum dimming is imposed?

✓	
---	--

133. Is bulb brightness clearly visible in indicator lights?

✓	
---	--

134. Are the indicator lights bright enough for the task at hand?

✓	
---	--

135. Is glare from the light source absent on indicated lights?

✓	
---	--

136. Is the background a dull finish and dark in contrast to the light?

✓	
---	--

137. Are lights which must attract immediate attention at least twice as bright as the immediate background?

✓	
---	--

138. Are red lights used where dark adaptation is necessary?

✓	
---	--

139. Are the displays evenly illuminated?

✓	
---	--

140. Do the instrument markings have a continuously controllable brightness range from .02 to 1.0 foot lamberts for night flying conditions?

✓	
---	--

141. Is the brightness of the surrounding area less than the visual task and at least 1/10 the brightness of the visual task?

✓	
---	--

142. Is a control provided to vary the brightness of indicators when the ambient illumination will vary?

✓	
---	--

143. If dark adaptation is not required, is the instrument lighting white flood lighting with a brightness range of the markings from 1 to 20 foot lamberts?

✓	
---	--

144. Is flood lighting used for dial type indicators?

N	A
---	---

IX. Labeling

145. Are all control and indicator labels consistent in meaning, i.e., do they all describe a condition, or do they all tell the operator to do something?

✓	
---	--

146. Do the display labels indicate information that is meaningful and useful to the operator?
147. Do the control labels indicate the use of-the control?
148. Do the labels of indicators used to indicate the steps in an operational sequence tell the operator "what to do" or "what is going to happen" and not "what has been done" or "what has happened"?
149. Do the labels convey the meaning that is intended and only that meaning?
150. Are all controls and displays identified by label?
151. Are all control and display movements identified by label?
152. Are associated controls and displays related by label?
153. Does the label on the control indicate the same use as the label on the display it affects?
154. Is the interpretation of the information displayed specifically indicated?
155. Is the direction to operate the control for a given effect indicated?
156. Is the direction to operate the control to produce a given display effect indicated?
157. Are adjustment controls requiring a positional reference indexed?
158. Are arrows used to indicate the direction of movement on adjustment knobs?
159. Are capital letters used for labels?
160. Is extended copy on the panel in lower case letters?
161. Are the labels short?
162. Are abbreviations avoided, where possible?

✓	
	✓
	✓
✓	
✓	
	✓
	✓
✓	
✓	
✓	
✓	
✓	
✓	
✓	
N	A
✓	
✓	

163.	Are the abbreviations used standard and familiar to the expected operator?	✓	
164.	Are the labels durable?	✓	
165.	Do all control and display labels use the same letter size?	✓	
166.	Are the labels indicating functional groups clearly larger than the control and display labels?	✓	
167.	Is the height of the numbers and letters 1/10 to 1/5 inch for a viewing distance of a maximum of 28 inches?	✓	
168.	Do white letters on a black background have a stroke width of 1/7 to 1/8 the height of the letters?	✓	
169.	Do black letters on a white background have a stroke width 1/6 the height of the letters?	N	H
170.	Does the number and letter design have simple configuration: contain no flourishes, have even stroke width, have vertical strokes of 90° and diagonal ones of 45°, have breaks and openings that are readily apparent?	✓	
171.	Is the height-width ratio of numbers and letters 3 to 2, except on spherical surfaces such as counters?	✓	
172.	Is the height-width ratio of numbers on counters 1 to 1?	✓	
173.	Are labels illuminated so that the ratio of the brightest to dimmest is less than 7 to 1?	✓	
174.	Are the labels easily read under the expected levels of illumination and viewing distances?	✓	
175.	Are the labels clearly separated from each other?	✓	
176.	Are the labels oriented horizontally?	✓	
177.	Can the labels be seen clearly from expected viewing angles?		✓

6. Redesign

After completion of the TOPC, link, and check list analysis and evaluation of the prototype design, a redesign of the Navigation Control Panel was made. The strong and weak points of the prototype design have been listed in detail. The redesign, therefore, was reduced to several well-defined problem areas. These include making the operator procedures less involved (TOPC), organizing the positions of controls and indicators for optimum operation (smoothing out the flow lines on the link analysis diagrams), and correcting as many as possible of the deficiencies on the human engineering check list. These problem areas were approached by the investigator with due consideration of their interrelationships.

The results of the link analysis indicated a lack of left-to-right, top-to-bottom ordering of operator data entry procedures. The solution to this deficiency was obtained by employing an additional data entry counter and repositioning the push buttons. The final push button positioning was obtained by using similar functional group association, see Figure 9.

The problem of inefficient use of push buttons could now be corrected. By providing an additional counter wheel on each data entry counter, the N-S and E-W designation of latitude and longitude could be provided, and the eight data entry push buttons could be reduced to two. Proper labeling of these two counters also provided a means of telling the operator how to use them for data entry functions.

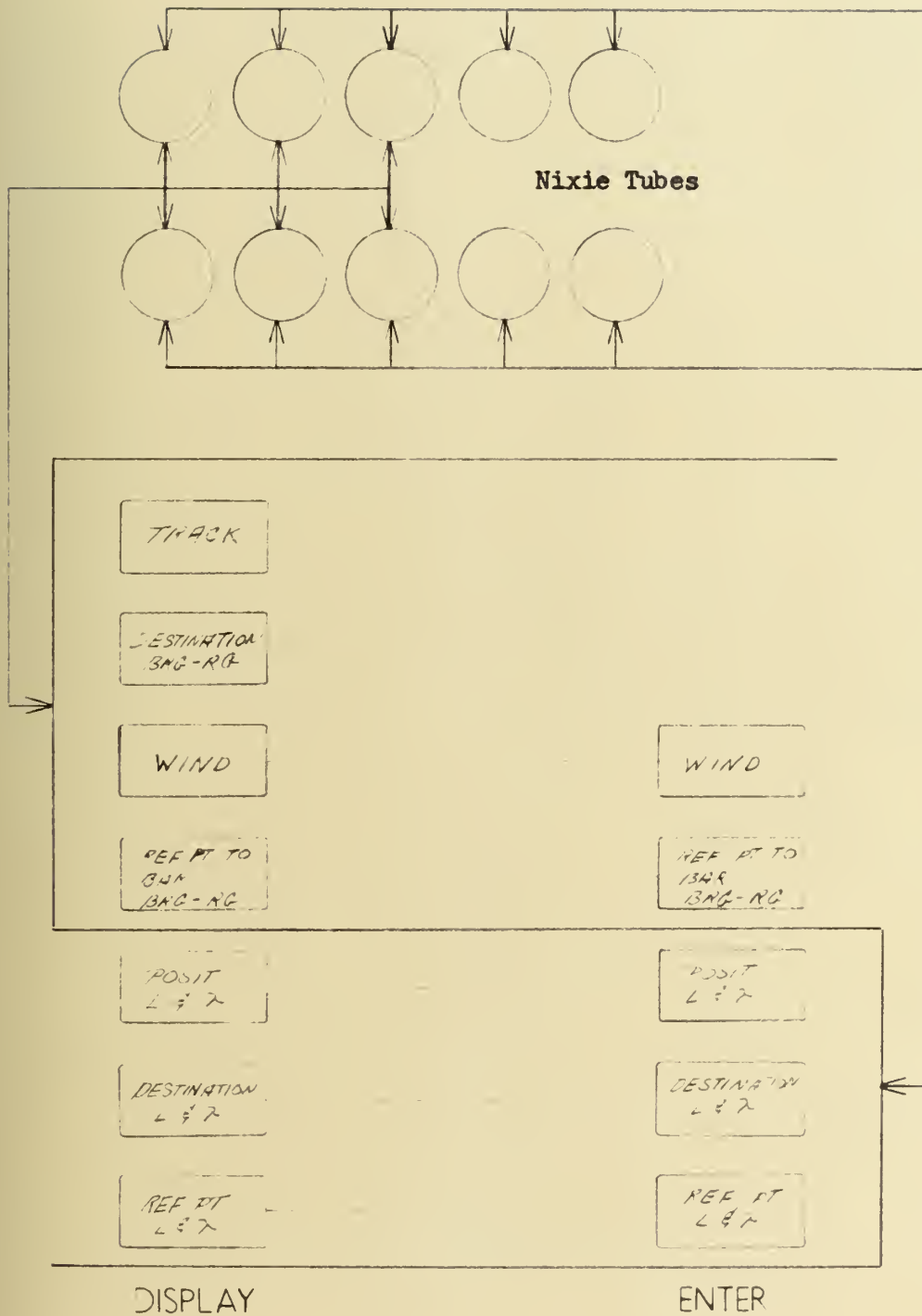


Figure 9. Navigation Panel Controls and Indicators
Functional Associations

Since the TOPC ("observed" item, page 31) showed no requirement for simultaneous numerical displays, the efficient use of the nixie tubes was realized by combining all display functions into two rows of nixie tubes and employing descriptive indicators at the end of each row. The space now made available by the elimination of two rows of nixie tubes and six push buttons was utilized to incline the remaining nixie tubes to a line of sight position. The use of the prisms was no longer required.

To further assist the operator in his data entry tasks, the illumination of the data entry counter wheels was modified. Counter wheel illumination is designed to only light those wheels which are used for the selected data entry quantity. As an example, when the WIND push button is pressed, the "bearing" and "speed" sections of the counter wheels are lighted (refer to step 12.1 of Redesign TOPC). When a latitude and longitude push button is pressed, the corresponding sections of the counter wheels illuminate.

During the redesign of the Nav-Panel an effort was made to incorporate all favorable features of the prototype design and still overcome its deficiencies. In addition, by understanding the electronic design it was possible to redesign the panel and still use existing logic and electronic circuits. The redesigned Navigation Control Panel is shown in Figure 10. The redesign was "completed" by making a Functional Description for the new panel controls and indicators to provide suitable data for the logical designers.

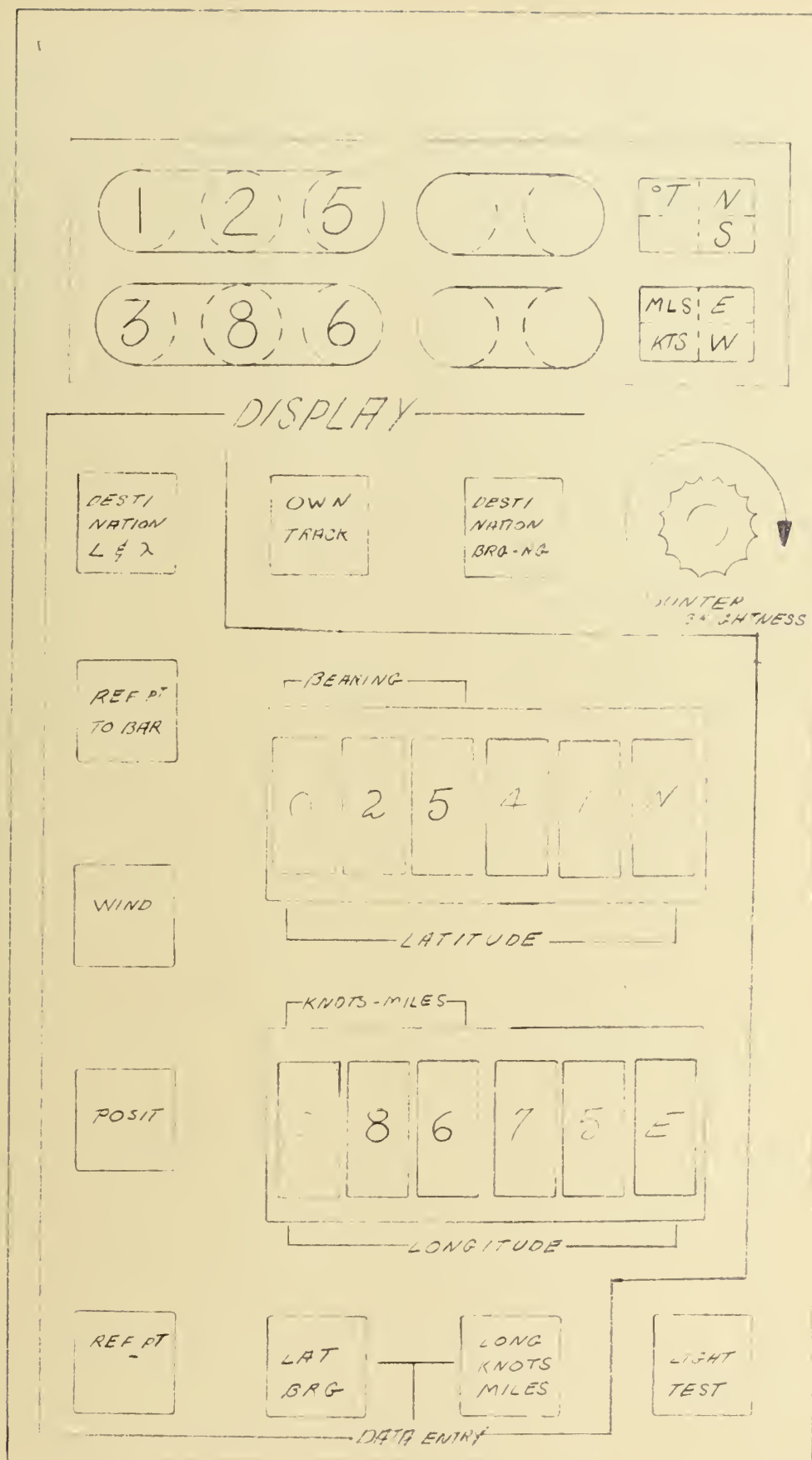


Figure 10. Navigation Control Panel redesign.

7. Analysis of Redesigned Navigation Control Panel

The three analysis procedures used to evaluate the prototype design were applied to the redesigned panel. A Functional Description (Appendix B) for the controls and indicators of the redesigned Nav-Panel had to be prepared before the new TOPC could be completed.

7.1 Tentative Operational Procedures Chart

The TOPC for the Nav-Panel redesign (pp 89-116) was completed using the Redesign Functional Description and the envisioned operation of the associated circuits. The circuit operation was discussed with the logic and electronics designers to ensure the feasibility of using the already developed basic circuit designs. To reiterate, the new design did permit the use of the logic and circuit designs developed for the prototype design.

TOPC Evaluation

A study of the completed TOPC for the Navigation Control Panel redesign leads to the following conclusions:

Desirable

- a. The design will perform all required display and data entry functions.
- b. All operator display functions are simple push button tasks, with operator feedback provided for every push button action.
- c. No machine times are excessive.
- d. Correction, or data entry of the five specified data entry functions is readily effected for all of a quantity (e.g., bearing and

range) or for part of it (e.g., bearing only).

e. Data entry functions are performed in one complete operation where the operator first sets up the data entry counter wheels to display the entire quantity and then effects the entry of the information into the Navigation Computer.

f. Selection of latitude designation, N or S, and longitude designation, E or W, is performed as a data entry counter wheel function immediately following the latitude and longitude figures to which these designations apply.

g. "Long term" storage of an entered (or to be entered) quantity is possible for a single quantity. Only one quantity may be stored at a time (not a specification item).

h. Machine functions are performed to indicate to the operator which data entry counter wheels are to be used for the various data entry quantities.

Undesirable

The actuation of any one of seven display push buttons places the two data entry push buttons in a "live" condition.

Observations

a. A maximum of one push button and the two rows of nixie tubes can be lighted at any one time.

b. No new logic or electronic circuit designs are required. The basic circuits developed for the prototype design can be used for instrumentation of the redesign.

REDESIGN TOPC

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	STEP
OPERATIONAL PROCEDURE	
Wind direction and speed display	1.0
Barrier reference point to barrier center bearing and range display	2.0
Destination bearing and range display	3.0
Track angle and ground speed display	4.0
Barrier reference point latitude and longitude display	5.0
Destination latitude and longitude display	6.0
Present position latitude and longitude display	7.0
Destination latitude and longitude data entry	8.0
Present position latitude and longitude data entry	9.0
Barrier reference point latitude and longitude data entry	10.0
Barrier reference point to barrier center bearing and range data entry	11.0
Wind direction and speed data entry	12.0
Nixie tube brightness adjustment	13.0
Light test	14.0

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIMES
1.0 Display wind direction and speed.				
1.1 Presses WIND push button.	<p data-bbox="189 204 350 1011">WIND button lights.</p> <p data-bbox="350 204 630 1011">BEARING and KNOTS-MILES sections of data entry counter wheels illuminate.</p> <p data-bbox="630 204 909 1011">OT and KTS indicators light.</p> <p data-bbox="909 204 1381 1011">1st and 2nd row nixie tubes change to display 3 numbers each in first 3 positions.</p>	<p data-bbox="189 1011 420 1835">The Nav-Panel interlock circuit acts to extinguish OWN TRACK, DESTINATION BRO-RG, DESTINATION L & A, REF PT TO BAR, POSIT, or REF PT push button if illuminated.</p> <p data-bbox="420 1011 630 1835">WIND illumination relay holding circuit is energized, closing relay.</p> <p data-bbox="630 1011 909 1835">Nav-Panel interlock circuit acts to extinguish right half of counter wheels if illuminated and energizes left half illumination relay holding circuit, closing relay.</p> <p data-bbox="909 1011 1381 1835">OT and KTS illumination relay holding circuits are energized, closing relays.</p> <p data-bbox="1381 1011 1400 1835">Closing WIND push button circuit sends the "display wind data" signal through an input buffer to the Identification and Selection Matrix. The matrix identifies the input wind display signal, and sends outputs to the Digital Display Programmer requesting the display of wind data. The programmer obtains coincidence with the wind direction and wind speed memory storage of the Navigation Computer, reads out this data in binary form and sends it to the binary-to-decimal converter. The output of the converter is sent to the Nixie Tube Grid Control circuit which applies voltages to the grids of the 1st and 2nd row of nixie tubes corresponding to the wind direction and speed stored in the computer memory. See Notes 1 and 2.</p>	M8	<p data-bbox="189 2013 420 2044">2-13 ms.</p> <p data-bbox="420 2013 630 2044">2-13 ms.</p> <p data-bbox="630 2013 909 2044">2-13 ms.</p> <p data-bbox="909 2013 1381 2044">.25-.33 sec.</p>

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIMES
1.2	Reads wind direction as the 3 numbers displayed in 1st row nixies and wind speed as the 3 numbers displayed in 2nd row nixies.	WIND button light extinguishes.	P3, C3	2-13 ms.
1.3	Presses WIND push button.	BEARING and KNOTS-MILES sections of data entry counter wheels are extinguished. OT and KTS indicators are extinguished. 1st and 2nd row nixies are extinguished.		
		WIND push button illumination relay holding circuit is opened. Left half counter wheel illumination relay holding circuit is opened. OT and KTS illumination relay holding circuits are opened. The "display wind data" signal to the input buffer is terminated. The output of the Identification and Selection Matrix is terminated. The output of the Digital Display Programmer to the binary-to- decimal converter is terminated and no signal is sent to the Nixie Tube Grid Control which causes the nixie tubes to be extinguished.		2-13 ms.
2.0	Display bearing and range from barrier ref- erence point to barrier center.			23-5 ms.-.33 sec

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIMES
2.1	Presses REF PT TO BAR push button.	<p>REF PT TO BAR button lights.</p> <p>BEARING and KNOTS-MILES sections of data entry counter wheels illuminate.</p> <p>OT and MLS indicators light.</p> <p>1st and 2nd row nixies change to display 3 numbers each in first 3 positions.</p>	<p>Nav-Panel interlock circuit acts to extinguish OMN TRACK, DESTINATION BRG-RG, DESTINATION L & λ, WIND, POSIT or REF PT push button if illuminated.</p> <p>REF PT TO BAR illumination relay holding circuit is energized, closing relay.</p> <p>Nav-Panel interlock circuit acts to extinguish right half of counter wheels if illuminated and energizes left half illumination relay holding circuit, closing relay.</p> <p>OT and MLS illumination relay holding circuits are energized, closing relays.</p> <p>Closing REF PT TO BAR push button circuit sends the "display REF PT TO BAR data" signal through an input buffer to the Identification and Selection Matrix. The matrix identifies the input signal and sends outputs to the Digital Display Programmer requesting the display of reference point to barrier range and bearing. The programmer obtains coincidence with the reference point to barrier range and bearing memory storage of the Navigation Computer and reads out this information in binary form. It is sent to a binary-to-decimal converter. The output of the converter goes to the Nixie Tube Grid Control circuit which applies voltages to the grids of the 1st and 2nd row of nixie tubes. The grids energized correspond to the reference point to barrier data stored in the computer memory.</p> <p>See Notes 1 and 2.</p>	<p>2-13 ms.</p> <p>2-13 ms.</p> <p>2-13 ms.</p> <p></p> <p></p> <p>.25-.33 sec.</p>

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIMES
2.2 Observes bearing (1st row nixies) and range (2nd row nixies) from barrier ref- erence point to barrier center.			P3, C3	
2.3 Presses REF PT TO BAR push button.	REF PT TO BAR button light extinguishes. OT and MLS indicator lights are extinguished. BEARING and KNOTS-MILES sections of data entry counter wheels are extinguished. 1st and 2nd row nixie tubes are extinguished.	REF PT TO BAR illumination relay holding circuit is opened. OT and MLS indicator illumination relay holding circuits are opened. Left half counter wheel illumination relay holding circuit is opened. The "display REF PT TO BAR data" signal to the input buffer is terminated. The output of the Identification and Selection Matrix is terminated. The output of the Digital Display Programmer to the binary-to-decimal converter stops and the Nixie Tube Grid Control circuit ceases to apply voltages to the 1st and 2nd row nixie tube grids.	P8	2-13 ms. 2-23 ms. 2-13 ms.
3.0 Display destination bearing and range.				23.5 ms.-.33 sec
3.1 Presses DESTINATION BRG- RG push button.	DESTINATION BRG-RG button lights.	The Nav-Panel interlock circuit acts to extinguish OWN TRACK, DESTINATION L & A, REF PT TO BAR, WIND, POSIT or REF PT push buttons if illuminated. DESTINATION BRG-RG, push button illumination relay holding circuit is energized, closing relay.	P9	2-13 ms.

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIMES
	<p>O_T and MLS indicators light.</p> <p>1st and 2nd row nixies change to display 3 numbers each in first 3 positions.</p>	<p>O_T and MLS indicator illumination relay holding circuits are energized, closing relays.</p> <p>Closing the DESTINATION BRO-EG push button circuit sends the "display destination range and bearing" signal through an input buffer to the Identification and Selection Matrix. The matrix identifies the input destination display signal, and sends outputs to the Digital Display Programmer requesting the display of destination data.</p> <p>The programmer obtains coincidence with the destination range and bearing memory storage of the Navigation Computer, reads out this data in binary form and sends it to the binary-to-decimal converter. The output of the converter is sent to the Nixie Tube Grid</p> <p>Control circuit which applies voltages to the grids of the 1st and 2nd row of nixie tubes corresponding to the destination range and bearing stored in the computer memory.</p> <p>See Notes 1 and 2.</p>		2-13 ms.
<p>3.2 Reads destination bearing (3 numbers displayed by 1st row nixies) and range (3 numbers displayed by 2nd row nixies).</p>			P3, C3	.25-.33 sec

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIMES
3.3	Presses DESTINATION L & A push button.	DESTINATION L & A button extinguishes. OT and MLS indicator lights are extinguished. 1st and 2nd row nixie tubes are extinguished.	DESTINATION L & A illumination relay holding circuit is opened. OT and MLS indicator illumination relay holding circuits are opened. The "display destination range and bearing data" signal to the input buffer is terminated. The output of the Digital Display Programmer to the binary-to-decimal converter is terminated and a signal sent to the Nixie Tube Grid Control to cause the nixie tubes to be extinguished.	2-13 ms. 2-13 ms.
4.0	Display track angle and ground speed.			23.5 ms.-.33 sec.
4.1	Presses OWN TRACK push button.	OWN TRACK button lights. OT and KTS indicators lights. light.	The Nav-Panel interlock circuit acts to extinguish DESTINATION BRG-RG, DESTINATION L & A , REF PT TO BAR, WNDD, POSIT, or REF PT push button if illuminated. OWN TRACK push button illumination relay holding circuit is energized, closing the relay. OT and KTS indicator illumination relay holding circuits are energized, closing the relay.	2-13 ms. 2-13 ms.

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIMES
	1st and 2nd row nixies change to display 3 numbers each in first 3 positions.	Closing OWN TRACK push button circuit sends "display track data" signal through an input buffer to the Identification and Selection Matrix. The matrix identifies the input track display signal, and sends outputs to the Digital Display Programmer requesting the display of track angle and ground speed. The programmer obtains coincidence with the track angle and ground speed memory storage of the Navigation- Computer, reads out the requested information in binary form and sends it to the binary-to-decimal converter. The output of the converter operates the Nixie Tube Grid Control circuit which applies voltages to the grids of the 1st and 2nd row of nixie tubes corresponding to the track angle and ground speed stored in the computer memory. See Notes 1 and 2.		.25--.33 sec.
4.2	Reads own track angle as 3 numbers displayed by 1st row nixies and ground speed as 3 numbers displayed by 2nd row nixies.		P3, C3	
4.3	Pushes OWN TRACK push button. OWN TRACK button is extinguished. OT and KTS indicators are extinguished.	OWN TRACK push button illumination relay holding holding circuit is opened. OT and KTS indicator illumination relay holding circuits are opened.	N3	2-13 ms. 2-13 ms.

			obtains coincidence with the reference point latitude and reference point longitude memory storage of the Navigation Computer, reads out the requested information in binary form and sends it to the binary-to-decimal converter. The output of the converter operates the Nixie Tube Grid Control which applies voltages to the grids of the 1st and 2nd row nixie tubes corresponding to the reference point latitude and longitude stored in the computer. The N or S and E or W indicators are lighted by closing their respective relay holding circuits with signals from the Nixie Tube Grid Control circuit.			.25-.33 sec.
5.2	Observes reference point latitude as 5 numbers followed by a letter displayed by 1st row nixies and longitude as 6 numbers followed by a letter displayed by 2nd row nixies.		See Notes 1 and 2.		P3, C3	
5.3	Pushes REF PT push button.	REF PT button extinguishes.	REF PT push button illumination relay holding circuit is opened.		N8	2-13 ms.
		Data entry counter wheels are extinguished.	"Left half" and "right half" data entry counter wheel illumination relay holding circuits are opened.			2-13 ms.

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSING PERFORMANCE TIMES
	1st and 2nd row nixies extinguish.	The "display reference point data" signal to the input buffer is terminated. The output of the Identification and Selection Matrix is terminated. The output of the Digital Display Programmer to the binary-to-decimal converter is terminated and no signal is sent to the Nixie Tube Grid Control circuit which causes the nixie tubes and N or S and E or W indicators to be extinguished.	23.5 ms.-.33 sec.
6.0	Display destination latitude and longitude.		13
6.1	Presses DESTINATION L & λ push button.	DESTINATION L & λ button lights.	The Nav-Panel interlock circuit acts to extinguish OWN TRACK, DESTINATION BRG-RNG, REF PT TO BAC, WIND, POSIT, or REF PT push button if illuminated. DESTINATION L & λ button illumination relay holding circuit is energized, closing relay.
	LATITUDE and LONGITUDE sections of data entry counter wheels illuminate (all wheels light).	"Left half" and "right half" counter wheel illumination relays are energized, closing relays.	2-13 ms.
	1st row nixies change to indicate 4 numbers followed by a letter (N or S) and 2nd row nixies change to indicate 5 numbers followed by a letter (E or W).	Closing DESTINATION L & λ push button circuit sends the "display destination latitude and longitude" signal through an input buffer to the Identification and Selection Matrix. The matrix identifies the input display destination data signal and sends outputs to the Digital Display Programmer requesting the display of destination latitude and longitude. The programmer obtains coincidence with the destination latitude and	2-13 ms.

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIMES
b.2	<p>Observes destination latitude as 5 numbers followed by a letter displayed by 1st row nixies and longitude as 6 numbers followed by a letter displayed by 2nd row nixies.</p>	<p>destination longitude memory storage of the Navigation Computer, reads out the requested information in binary form and sends it to the binary-to-decimal converter. The output of the converter operates the Nixie Tube Grid Control which applies voltages to the grids of the 1st and 2nd row nixie tubes and operates the N or S and E or W illumination relay holding circuits corresponding to the destination latitude and longitude stored in the computer.</p> <p>See Notes 1 and 2.</p>	<p>P3, C3</p>	<p>.25-.33 sec.</p>
b.3	<p>Presses DESTINATION L & A push button.</p>	<p>DESTINATION L & A button extinguishes.</p> <p>Data entry counter wheels are extinguished.</p> <p>1st and 2nd row nixies N or S and E or W indicators extinguish.</p>	<p>DESTINATION L & A push button illumination relay holding circuit is opened.</p> <p>"Left half" and "right half" data entry counter wheel illumination relay holding circuits are opened.</p> <p>The "display destination latitude and longitude" signal to the input buffer is terminated. The output of the Identification and Selection Matrix is terminated.</p> <p>The output of the Digital Display Programmer to the binary-to-decimal converter is terminated and no signal</p>	<p>M8</p> <p>2-13 ms.</p> <p>2-13 ms.</p>

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIMES
7.0 Display present position latitude and longitude.		is sent to the Nixie Tube Grid Control circuit which causes the nixie tubes and indicators to be extinguished.		23.5-.33 sec.
7.1 Presses POSIT push button.	<p data-bbox="329 1141 351 1359">POSIT button lights.</p> <p data-bbox="608 1048 751 1359">LATITUDE and LONGITUDE section of data entry counter wheels illuminate (all wheels light).</p> <p data-bbox="793 1048 1022 1359">1st row nixies change to in- dicate 4 numbers followed by a letter (N or S) and 2nd row nixies change to indicate 5 numbers followed by a letter (E or W).</p>	<p data-bbox="329 468 479 996">The Nav-Panel interlock circuit acts to extinguish OWN TRACK, DESTINATION ERG-RG, DESTINATION L & λ, REF PT TO BAR, WIND or REF PT push button if illuminated.</p> <p data-bbox="501 488 565 996">POSIT illumination relay holding circuit is energized, closing relay.</p> <p data-bbox="608 426 672 996">"Left half" and "right half" counter wheel illumination relays are energized, closing relays.</p> <p data-bbox="793 447 1279 996">Closing POSIT push button circuit sends the "display position data" signal through an input buffer to the Identification and Selection Matrix. The matrix identifies the input display position data signal and sends outputs to the Digital Display Programmer requesting the display of present position latitude and longitude. The programmer obtains coincidence with the position latitude and position longitude memory storage of the Navigation Computer, reads out the requested information in binary form and sends it to the binary-to-decimal converter. The output of the converter operates the Nixie Tube Grid Control which</p>	MS	2-13 ms.

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESS	PERFORMANCE TIMES
7.2 Observes present latitude (1st row nixies) as 4 numbers (degrees and minutes) followed by a letter (N or S) and longitude (2nd row nixies) as 5 figures (degrees and minutes) followed by a letter (E or W).		applies voltages to the grids of the 1st and 2nd row nixie tubes, N or S and E or W indicators, corresponding to the present position latitude and longitude stored in the computer. See Notes 1 and 2.	P3, C3	.25-.22 sec.
7.3	Presses POSIT push button. POSIT button extinguishes. Data entry counter wheels are extinguished. 1st and 2nd row nixies and indicators are extinguished.	POSIT push button illumination relay holding circuit is opened. "Left half" and "right half" data entry counter wheels illumination relay holding circuits are opened. The "display position data" signal to the input buffer is terminated. The output of the Identification and Selection Matrix is terminated. The output of the Digital Display Programmer to the binary-to-decimal converter is terminated and no signal is sent to the Nixie Tube Grid Control circuit which causes the nixie tubes and indicat- ors to be extinguished.	N9	2-2.3 ms. 2-1.3 ms.
8.0	Enter destination latitude and longitude.			23.5-.33 ms.

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIMES
S.1 Presses DESTINATION L & λ push button.	DESTINATION L & λ button lights. LATITUDE and LONGITUDE sections of data entry counter wheels illuminate (all wheels light). 1st row nixies change to indicate 4 numbers followed by a letter (N or S) and 2nd row nixies change to indicate 5 numbers followed by a letter (E or W).	See 6.1.	M8	2-13 ms. 2-13 ms.
S.2 Observes latitude (1st row nixies) and Longitude (2nd row nixies) of destination now present in the Nav- igation Computer Memory.			P3	.25-.33 ms.
S.3 Decides the latitude and longitude of destination is incorrect and to enter new data.			C3	
S.4 Positions the 1st row (latitude section) DATA ENTRY counter wheels to display correct destination latitude (1st wheel set to "Blank"; 2nd and 3rd set to degrees; 4th and 5th set			M8, C3	

<p>to minutes; 6th wheel set to N or S). Positions the 2nd row DATA ENTRY counter wheels to display correct destination longitude (1st, 2nd, and 3rd set to degrees; 4th and 5th set to minutes; and 6th wheel set to E or W).</p>				<p>6.15 sec.</p>
<p>5.5 Presses LAT-BRG push button. See Note 3.</p>	<p>1st row nixies change to display 4 numbers followed by the N or S indicator corresponding to the settings of the 1st row counter wheels.</p>	<p>Pressing the LAT-BRG push button actuates the 1st row DATA ENTRY Counter Wheel Sampling circuit. The 6 counter wheels are sampled sequentially and signals corresponding to their settings are sent to a decimal-to-binary converter. The output of the converter is entered in the Navigation Computer memory storage as destination latitude. The computer display procedures of step 6.1 is performed and the 1st row nixie tube grids are energized corresponding to the latitude that has been entered in the computer memory.</p>	<p>M8</p>	<p>.25-.5 sec.</p>
<p>5.6 Presses LONG-KNOTS-MILES push button. See Note 3.</p>	<p>2nd row nixies change to display 5 numbers followed by the E or W indicator corresponding to the settings of the 2nd row counter wheels.</p>	<p>Pressing the LONG-KNOTS-MILES push button actuates the 2nd row DATA ENTRY Counter Wheel Sampling circuit. The 6 counter wheels are sampled sequentially and signals corresponding to their settings are sent to a decimal-to-binary converter. The output of the converter is entered in the Navigation Computer memory storage as destination longitude. The computer display procedure of step 6.1 is performed and the 2nd row nixie tube grids are energized corresponding to the longitude that has been entered in the computer memory.</p>		<p>.25-.5 sec.</p>

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIMES
8.7 Observes display of entered destination latitude and longitude by nixie tubes. Decides the displayed data is correct and data entry operation is complete.			P3, C3	
8.8 Presses DESTINATION L & λ push button.	DESTINATION L & λ button extinguishes. Data entry counter wheels are extinguished. 1st and 2nd row nixies and indicators are extinguished.	See 6.3.	1.0	2-13 ms. 2-13 ms. 23.5-.33 sec.
9.0 Enter present position latitude and longitude.				
9.1 Presses POSIT push button.	POSIT button lights. . LATITUDE and LONGITUDE section of DATA ENTRY counter wheels illuminate (all wheels light). 1st row nixies change to indicate 4 numbers followed by a letter (W or S) and 2nd row nixies change to indicate 5 numbers followed by a letter (E or W).	See 7.1.	MS	2-13 ms. 2-13 ms. .25-.33 sec.

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIMES
9.2 Observes present position now in the Navigation Computer memory as latitude in degrees and minutes, N or S (1st row nixies) and longitude in degrees and minutes, E or W (2nd row nixies).			P3	
9.3 Decides the latitude and longitude of present position is incorrect and to enter new data.			C3	
9.4 Positions the 1st row (Latitude section) DATA ENTRY counter wheels to display correct present position latitude (1st wheel set to "Blank"; 2nd and 3rd set to degrees; 4th and 5th set to minutes; 6th wheel set to N or S). Positions the 2nd row (Longitude section) DATA ENTRY counter wheels to display correct position longitude (1st, 2nd, and 3rd set to degrees; 4th and 5th set to minutes; 6th wheel set to E or W).			M ⁰ , C3	6-15 sec.

9.5	Presses LAT-BRG push button.	1st row nixies change to display 4 numbers followed by a letter (N or S) corresponding to the settings of the 1st row counter wheels.	Pressing the LAT-BRG push button actuates the 1st row DATA ENTRY Counter Wheel Sampling circuit. The 6 counter wheels are sampled sequentially and signals corresponding to their settings are sent to a decimal-to-binary converter. The output of the converter is entered in the Navigation Computer memory storage as position latitude. The computer display procedure of step 7.1 is performed and the 1st row nixie tube grids are energized corresponding to the latitude that has been entered in the computer memory.	MS	.25-.5 sec.
9.6	Presses LONG-KNOTS-MILES push button. See Note 3.	2nd row nixies change to display 5 numbers followed by a letter (E or W) corresponding to the settings of the 2nd row counter wheels.	Pressing the LONG-KNOTS-MILES push button actuates the 2nd row DATA ENTRY Counter Wheel Sampling circuit. The 6 counter wheels are sampled sequentially and signals corresponding to their settings are sent to a decimal-to-binary converter. The output of the converter is entered in the Navigation Computer memory storage as position longitude. The computer display procedure of step 7.1 is performed and the 2nd row nixie tube grids are energized corresponding to the longitude that has been entered in the computer memory.	MS	
9.7	Observes display of entered present position latitude and longitude by nixie tubes. Decides the displayed data is correct and data entry operation is complete.			P3, C3	.25-.5 sec.

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIME
9.5	Presses POSIT push button.	See 7.3.	N3	2-13 ms.
10.0	Enter barrier reference point latitude and longitude.	Data entry counter wheels are extinguished. 1st and 2nd row nixie tubes and indicators are extinguished.		2-13 ms.
10.1	Presses REF PT push button.	See 5.1.	N3	2-13 ms.
10.2	Observes latitude (1st row nixies) and longitude (2nd row nixies) of barrier reference point now present in Navigation Computer memory.	LATITUDE and LONGITUDE sections of data entry counter wheels illuminate (all wheels light). 1st row nixie tubes change to display 4 numbers followed by a letter (N or S) and 2nd row nixies change to display 5 numbers followed by a letter (E or W).	P3	.25-.33 sec.

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIMES
10.3	Decides the latitude and longitude of the barrier reference point is incorrect and to enter new data.		C3	
10.4	Positions the 1st row (Latitude section) DATA ENTRY counter wheels to display correct barrier reference point latitude (1st wheel to "Blank", 2nd and 3rd set to degrees; 4th and 5th set to minutes; 6th wheel set to N or S). Positions the 2nd row (Longitude section) DATA ENTRY counter wheels to display correct barrier reference point longitude (1st, 2nd, and 3rd wheels set to degrees; 4th and 5th set to minutes; 6th wheel set to E or W).		M3, C3	
10.5	Presses LAT-ERG push button. See Note 3.	1st row nixies change to display 4 numbers followed by a letter (N or S) corresponding to the settings of the 1st row counter wheels.	M3	6-15 sec.

Pressing the LAT-ERG push button actuates the 1st row Data Entry Counter Wheel Sampling circuit. The 6 counter wheels are sampled sequentially and signals corresponding to their settings are sent to a decimal-to-binary converter. The output of the converter is entered in the Navigation Computer memory storage as barrier reference point latitude.

			<p>The computer display procedure of step 5.1 is performed and the 1st row nixie tube grids are energized corresponding to the latitude that has been entered in the computer memory.</p>	
10.6	<p>Presses LONG-KNOTS-MILES push button.</p> <p>See Note 3.</p>	<p>2nd row nixies change to display 5 numbers followed by a letter (E or W) corresponding to the settings of the 2nd row counter wheels.</p>	<p>Pressing the LONG-KNOTS-MILES push button actuates the 2nd row Data Entry Counter Wheel Sampling circuit.</p> <p>The 6 counter wheels are sampled sequentially and signals corresponding to their settings are sent to a decimal-to-binary converter. The output of the converter is entered in the Navigation Computer memory storage as present position longitude. The computer display procedure of step 5.1 is performed and the 2nd row nixie tube grids are energized corresponding to the longitude that has been entered in the computer memory.</p>	.25-.5 sec.
10.7	<p>Observes display of entered barrier reference point latitude and longitude by nixie tubes.</p> <p>Decides the displayed data is correct and data entry operation is complete.</p>		P3, C3	.25-.5 sec.
10.8	<p>Presses REF PT push button.</p>	<p>REF PT button extinguishes.</p> <p>Data entry counter wheels are extinguished.</p> <p>1st and 2nd row nixies and indicators are extinguished.</p>	<p>See 5.3.</p>	<p>2-13 ms.</p> <p>2-13 ms.</p> <p>23.5 ms.-.33 sec.</p>

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIMES
11.0	Enter barrier reference point to barrier center bearing and range.			
11.1	Presses REF PT TC BAR push button.	REF PT TO BAR button lights. OT and MLS indicators light. BEARING and KNOTS-MILES sections of DATA ENTRY counter wheels light (first 3 wheels of each row). 1st and 2nd row nixies change to display 3 numbers each in first 3 positions.	M8	2-13 ms. 2-13 ms. 2-13 ms.
11.2	Observes bearing (1st row nixies) and range (2nd row nixies) from barrier reference point to barrier center now in Navigation Computer.		P3	.25-.33 sec.
11.3	Decides the displayed data is incorrect and to change it.		C3	
11.4	Positions the 1st, 2nd, and 3rd wheels of the 1st row (BEARING section) DATA ENTRY counter wheels to display correct bearing from barrier		M8, C3	

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIMES
reference point to barrier center. Positions the 1st, 2nd, and 3rd wheels of the 2nd row (KNOTS-MILES section) DATA ENTRY counter wheels to display correct range (in miles) from barrier reference point to barrier center.				
11.5 Presses LAT-ERG push button. See Note 3.	1st row nixie tubes change to display 3 numbers.	Pressing the LAT-ERG push button actuates the 1st row Data Entry Counter Wheel Sampling circuit. The first 3 counter wheels are sampled sequentially and signals corresponding to their settings are sent to a decimal-to-binary converter. The output of the converter is entered in the Navigation Computer memory storage as barrier reference point to barrier center bearing. The computer display procedure of step 2.1 is performed and the 1st row nixie tube grids are energized corresponding to the bearing that has been entered in the computer memory.	M3	6-15 sec.
11.6 Presses LONG-KNOTS-MILES push button. See Note 3.	2nd row nixie tubes change to display 3 numbers.	Pressing the LONG-KNOTS-MILES push button actuates the 2nd row Data Entry Counter Wheel Sampling circuit. The first 3 counter wheels are sampled sequentially and signals corresponding to their settings are sent to a decimal-to-binary converter. The output of the converter is entered in the Navigation Computer memory storage as barrier reference point to barrier center	M3	.25-.5 sec.

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIMES
11.7	Observes display of barrier reference point to barrier center bearing and range. Decides the displayed data is correct and the data entry operation complete.	range. The computer display procedure of step 2.1 is performed and the 2nd row nixie tube grids are energized corresponding to the bearing that has been entered in the computer memory.	P3, C3	.25-.5 sec.
11.8	Presses REF PT TO BAR push button. REF PT TO BAR button extinguishes. OT-MLS indicators extinguish. BEARING and KNOTS-MILES section of DATA ENTRY counter wheels extinguish. 1st and 2nd row nixie tubes and indicators are extinguished.	See 2.3.	M8	2-13 ms. 2-13 ms. 2-13 ms. 23.5 ms.-.33 sec.
12.0	Enter wind direction and speed.	See 1.1.	M8	2-13 ms. 2-13 ms. 2-13 ms.
12.1	Presses WIND push button. WIND button lights. OT and KTS indicator lights. BEARING and KNOTS-MILES section of DATA ENTRY counter wheels illuminate.	See 1.1.	M8	2-13 ms. 2-13 ms. 2-13 ms.

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIMES
	1st and 2nd row nixies change to display 3 numbers each.			.25-.33 sec.
12.2 Observes wind direction (1st row nixies) and wind speed (2nd row nixies) now in computer.			P3	
12.3 Decides the displayed data is incorrect and to change it.			C3	
12.4 Positions the 1st, 2nd, and 3rd wheels of the 1st row (BEARING section) DATA ENTRY counter wheels to display correct wind direction. Positions the 1st, 2nd and 3rd wheels of the 2nd row (KNOTS-MILES section) DATA ENTRY counter wheels to dis- play correct wind speed.			M8, C3	
12.5 Pushes LAT-BRG push button. See Note 3.	1st row nixies change to dis- play 3 numbers corresponding to the BEARING section counter wheel settings.	Pressing the LAT-BRG push button actuates the 1st row Data Entry Counter Wheel Sampling circuit. The first 3 counter wheels are sampled sequentially and signals corresponding to their settings are sent to a decimal- to-binary converter. The output of the converter is entered in the Navigation Computer memory storage as wind direction. The computer display procedure of step 1.1 is performed and the 1st row nixie tube grids are energized corresponding to the wind direction that has been entered in the computer memory.	M8	6-15 sec.

.25-.5 sec.

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIMES
<p>12.6</p> <p>Presses LONG-KNOTS-MILES push button.</p> <p>See Note 3.</p>	<p>2nd row nixies change to display 3 numbers corresponding to the KNOTS-MILES counter wheel settings.</p>	<p>Pressing the LONG-KNOTS push button actuates the 2nd row Data Entry Counter Wheel Sampling circuit. The first 3 counter wheels are sampled sequentially and signals corresponding to their settings are sent to a decimal-to-binary converter. The output of the converter is entered in the Navigation Computer memory storage as wind speed. The computer display procedure of step 1.1 is performed and the 2nd row nixie tube grids are energized corresponding to the wind speed that has been entered in the computer memory.</p>	<p>M8</p>	<p>.25-.5 sec.</p>
<p>12.7</p> <p>Observes display of wind direction and wind speed entered in the Navigation Computer. Decides the entered data is correct and the entry operation complete.</p>			<p>P3, C3</p>	
<p>12.8</p> <p>Presses WIND push button.</p>	<p>WIND button extinguishes.</p> <p>OT-KTS indicators extinguish.</p> <p>BEARING and KNOTS-MILES sections of data entry counter nixies extinguish.</p> <p>1st and 2nd row nixie tubes are extinguished.</p>	<p>See 1.3.</p>	<p>M9</p>	<p>2-13 rs.</p> <p>2-13 rs.</p> <p>2-13 rs.</p> <p>23.5 ms.-.33 sec.</p>

OPERATOR PROCEDURES AND CRITERIA	NORMAL DISPLAY AND CONTROL	RELATIONAL SPECIFICATIONS	PSYCHOLOGICAL PROCESSES	PERFORMANCE TIMES
<p>13.0 Nixie tube brightness adjustment.</p> <p>14.0 Light test.</p>	<p>Identical to corresponding sections of TOPC for Prototype Design No. 1.</p>			
<p>Note 3: LAT-BRG and LONG-KNOTS-MILES push buttons are positioned to permit two-finger simultaneous operation of both buttons. For single entry either button may be actuated separately.</p>		<p>Note 1: Either row of nixie tubes may light first, since the display operation is performed sequentially and the information is stored in separate Navigation Computer memory storage.</p> <p>Note 2: The above readout procedure is repeated approximately every .3 seconds; as new data is inserted in the memory storage by the computer it is processed and different grids of the nixie tubes are energized corresponding to the new data.</p>		

7.2 Link Analysis

Using the completed redesign TOPC as a guide, a link analysis for the five data entry procedures was performed. Figures 11 through 15 are the link analysis diagrams for the five data entry functions.

Link Analysis Evaluation

From a study of the five link analysis diagrams the following conclusions are drawn:

- a. No disruption in operator procedures exists. Each data entry function consists of:

Push button operation.....a select function

Counter wheel manipulation.....a positioning function

Push button operation.....an enter function

- b. A left-to-right and top-to-bottom sequence of actions is effected.

- c. Control grouping for data entry functions is reasonably good.

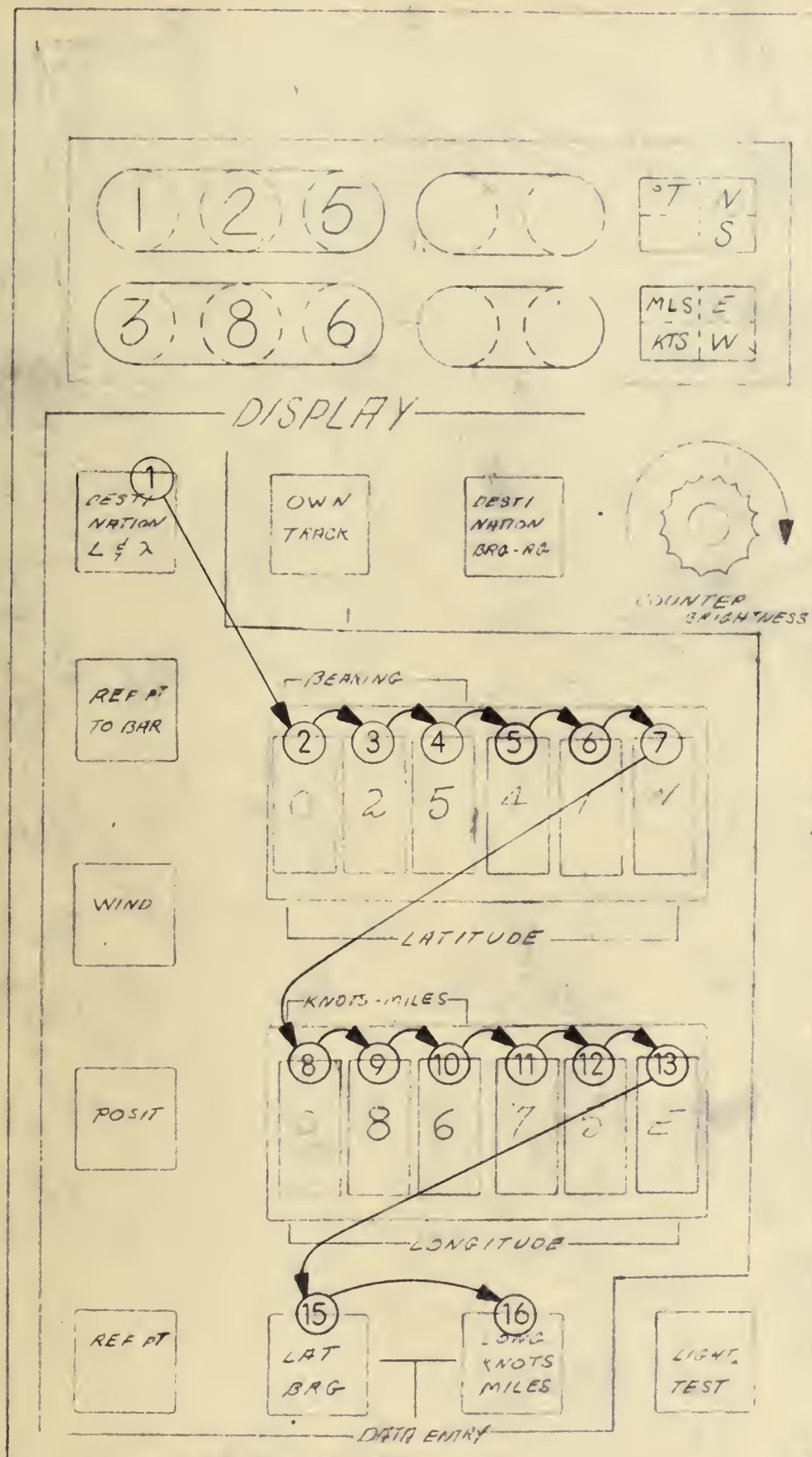
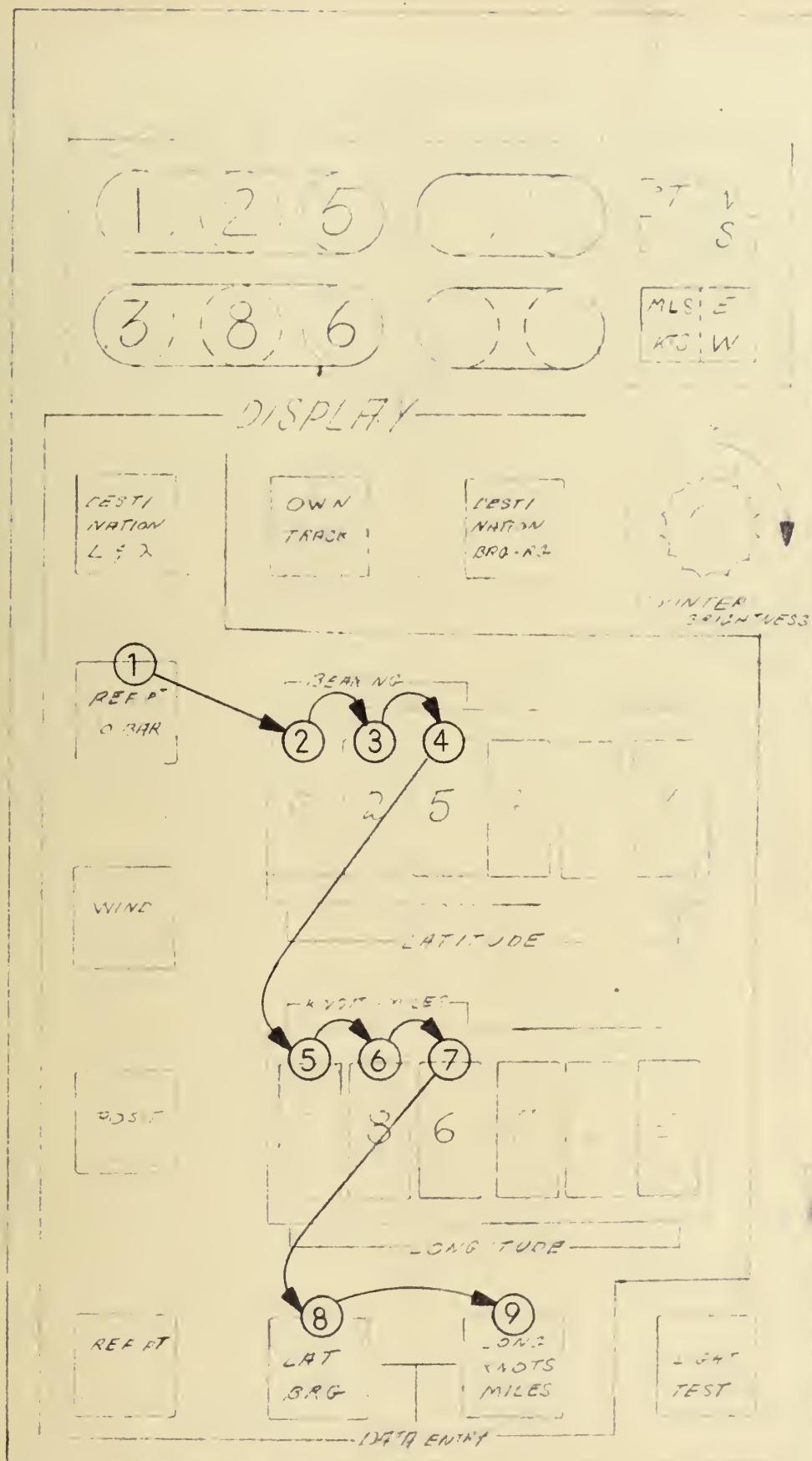


Figure 11. Link Analysis - Enter destination latitude and longitude.



REDESIGN

Figure 12. Link Analysis - Enter reference point to barrier center bearing and range.

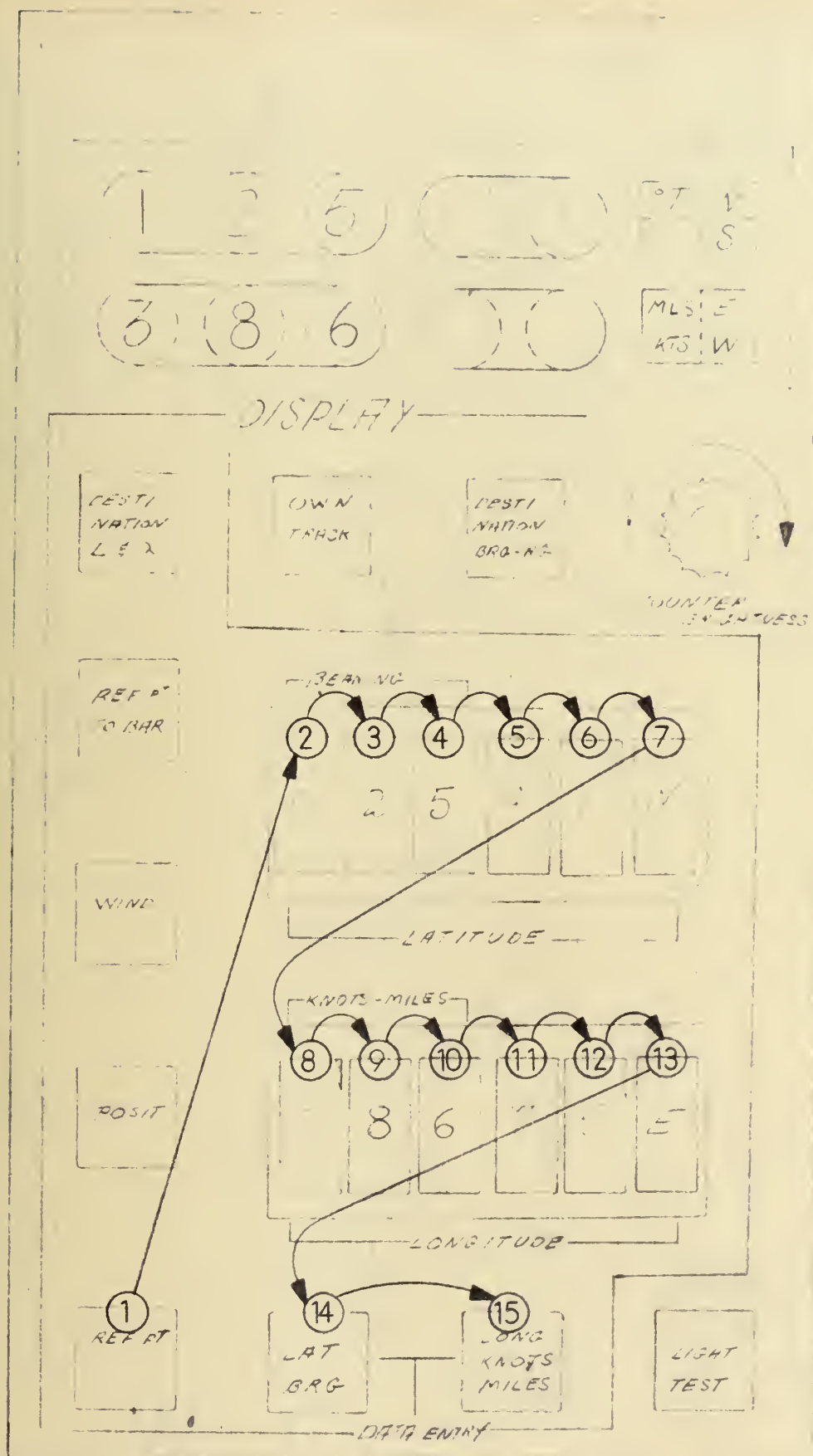
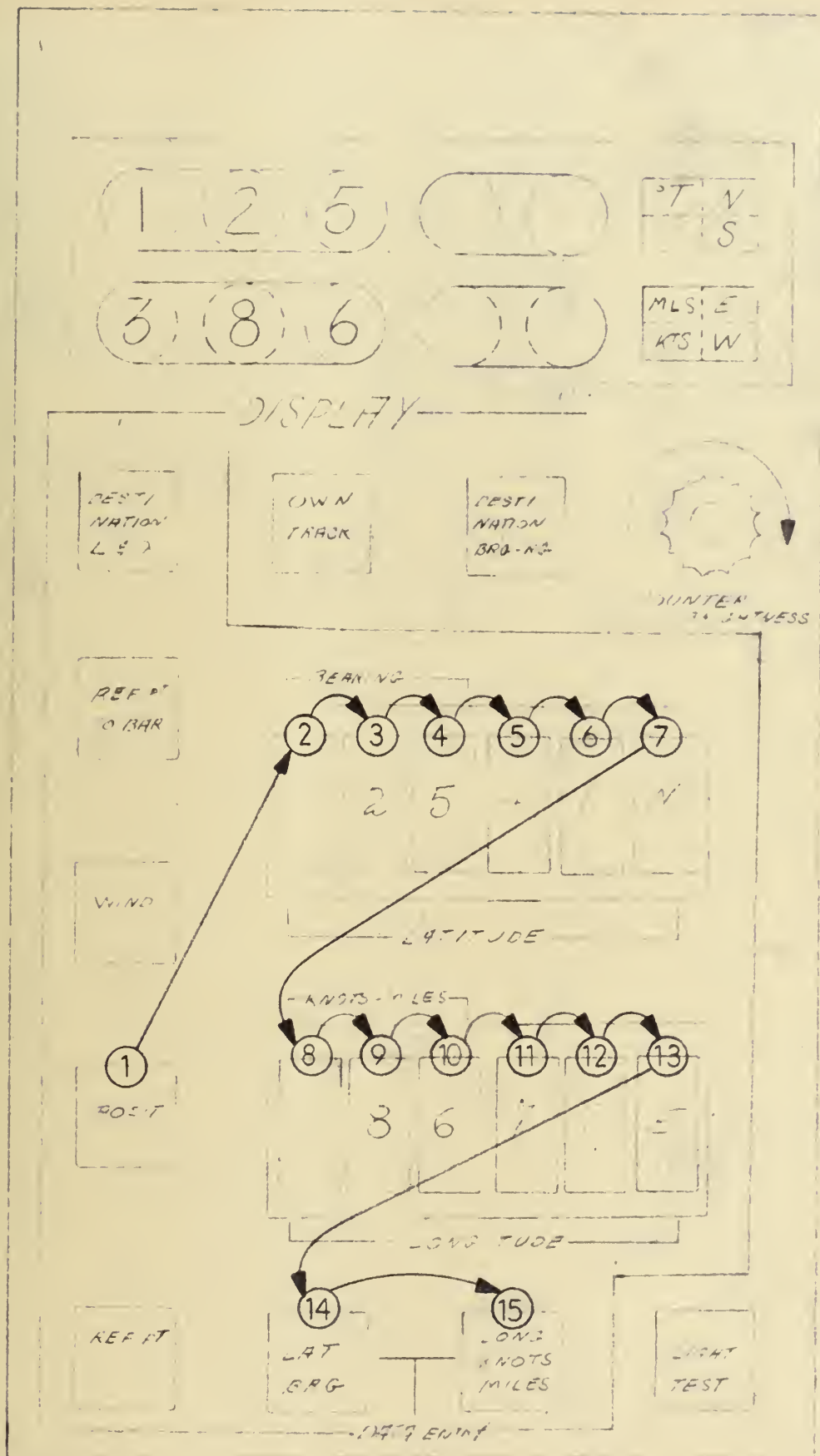
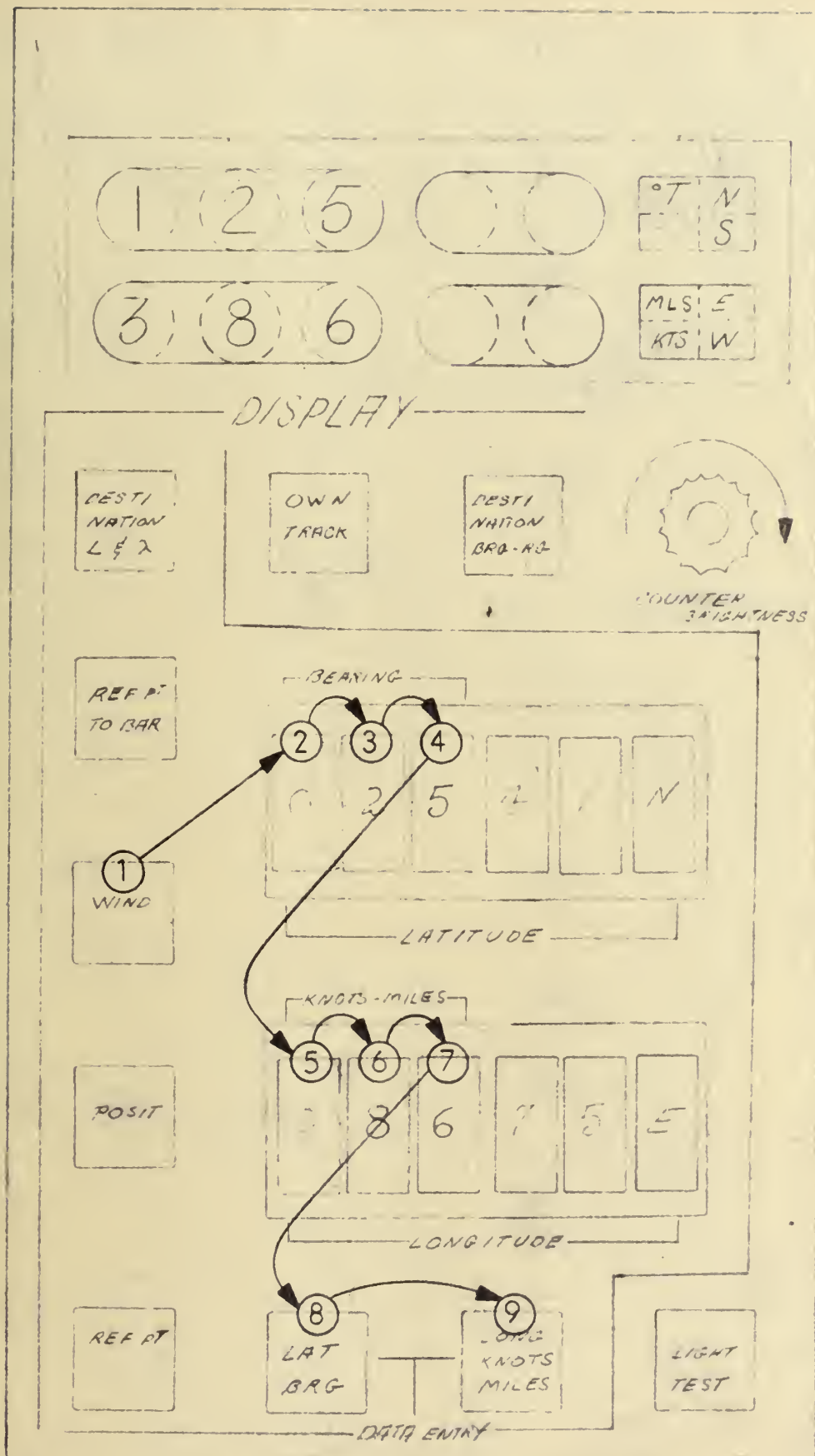


Figure 13. Link Analysis - Enter barrier reference point latitude and longitude.



REDESIGN

Figure 14. Link Analysis - Enter present position latitude and longitude.



REDESIGN

Figure 15. Link Analysis - Enter wind direction and speed.

7.3 Human Engineering Check List Analysis

The same check list used to evaluate the prototype design is applied to the redesign. In using the check list on the redesigned Nav-Panel, consideration is given to item improvement. Thus, if an item has been considerably improved over the prototype design and there is no presently available or known technique to further improve the described condition, it is checked "yes." This consideration is not applied to statements that can only be answered with an unqualified "yes" or "no."

Human Engineering Check List Evaluation

The results of the check list analysis of the redesigned Nav-Panel follow. Only deficient items are discussed.

a. Critical push buttons (data entry) are not recessed or provided with safety guards. There is no protection against accidental manipulation. Items 2 and 32.

b. Information is not presented to the operator so that the need for correlation is avoided. The operator must correlate the displayed figures with a lighted push button. Item 33.d.

c. Frequently used controls are not mounted forward, between elbow and shoulder height, off-center in line with arm plane, and near working position. Item 101.

CHECK LIST FOR REDESIGN

I. Controls

A. Push Buttons

1. Do the push buttons have a click contact?
2. Are critical push buttons recessed or provided with safety guards?
3. Do the push buttons require less than 40 oz. force for momentary pushing?
4. Do the push buttons require a maximum of 25 Oz. force for continuous pushing?
5. Do the push buttons use a pushing surface of at least 1/2 inch in diameter?
6. Are push button switches used for one or two discrete positions?

B. Adjustment Knobs

7. Are adjustment knobs that are used for non-critical or coarse adjustments approximately 1 inch in diameter?
8. Are round knobs used for controls requiring smooth continuous movement?
9. Do adjustment knobs give definite resistance to movements yet can be turned smoothly for short distances?
10. Do adjustment-type knobs use very light torque? (Approximately 2 inch lbs.)
11. Are knobs less than 3/4 inch in depth knurled?
12. Are knobs more than 3/4 inch in depth serrated?
13. Do serrated knobs have evenly spaced serrations and pointed edges?

II. General Considerations

14. Are all of the controls necessary to the operator in performing his task?
15. Are controls that follow in sequence interlocked so that they cannot be activated prematurely?
16. Where possible, is only one control used to set up a given condition or perform a given function?

YES	NO
✓	
	✓
✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	
N	A
N	A
✓	
✓	
✓	

17. Does a given control produce the same effect under different conditions?
18. Are controls located so that control movements avoid contact with equipment that could cause injury?
19. Are control movements free of obstructions?
20. Are control movements unkindered by clothing or personal equipment?
21. Is malfunctioning of a control obvious to the operator?
22. Are as few control movements as possible used?
23. Are controls requiring long periods of manipulation and small adjustments mounted so that the hand has a resting place?
24. Does the control consistently produce one effect for a given manipulation?
25. Are control actions positive without being sticky or stiff?
26. Are all control functions well within the limits of the physical strength of the population of operators?
27. Is shape coding used on controls that must be identified without visual aid?
28. Do the controls have a positive indication that they have been correctly positioned?
29. Do control movements to the left, counter-clockwise or down produce effects of left, off, or decrease, or negative increase?
30. Do controls appear to fit the job for which they are intended? (If there is little pressure required they should not be big and bulky, and if a lot of pressure or speed is required they should not appear fragile.)
31. Do control movements to the right, clockwise or up produce effects of right, on, or increase, or negative decrease?
32. Do critical controls provide protection against accidental manipulation?

✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	
N	A
✓	
✓	
✓	
✓	
✓	
	✓

III. Information Presentation

A. General Considerations

33. Is information presented to the operator so that the need for the following activities is avoided?
- a. sorting or assembling information
 - b. making routine calculations on data
 - c. translating or transposing information
 - d. correlating information
 - e. making predictions on the basis of information
34. Are judgments required of the operator kept to a minimum?
35. Is the need for an action by the operator and the specific action required indicated by a display?
36. Do the instruments permit direct interpretation and use of the information presented?
37. Do displays of similar information permit similar interpretation?
38. Is information presented to the operator so that there is only one possible interpretation?
39. Does a given indication have only one meaning?
40. Do the instruments present the required information in the most meaningful form?
41. Is the information presented to a single operator unduplicated except in the following situations?
- a. where its relationship in the sequencing of operation varies
 - b. where it is required when the operator's attention is focused in different areas
42. Is all the information displayed essential for the operator to complete his task?
43. Is information presented to the operator only if it is required for his use in performing the required operations or tasks?

✓	
✓	
✓	
	✓
✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	

44. Is the presentation of unnecessary information avoided?
45. Is all necessary information shown?
46. Does a single indicator display only one kind of information?
47. Is all information presented on a single display related?
48. Do the operational displays or associated indicators indicate equipment malfunctioning?
49. Is non-operation of the equipment indicated?
50. Is the need for a correction or change in the system indicated to the operator in sufficient time so that he may prepare to execute the required action?
51. Is the warm-up or "ready to go" condition of the equipment indicated?
52. Are crucial visual checks identified by attention-getting devices?
53. Are changes in display easy to detect?
54. Is the displayed information presented without lag behind the function being displayed?
55. Is parallax avoided in displays?
56. Is equipment easy to set up for operation?

B. Indicator Lights

57. Are indicator lights used for presenting just a few discrete conditions such as "ON-OFF" or "GOOD BAD"?
58. Do indicator lights used to present a given condition go "on" to indicate that condition?
59. Is a light going "off" to indicate a required action avoided?
60. Are indicator lights that are not controlled by the operator or are not generally off kept at a minimum?
61. Do warning signals remain on until the unfavorable condition is corrected?

✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	
N	A
✓	
N	A

62. Does an indicator light indicating a given condition remain on as long as the condition exists?

63. Do lights indicating a desired condition remain on as long as the condition is used?

64. Does an indicator light indicating a given condition go off when that condition no longer exists?

65. Do indicator lights remain on long enough to be detected under all anticipated circumstances?

66. Are flashing warning lights used when they are located peripheral to the central area of sight?

67. Are flashing lights used when immediate attention is required?

68. Is the flash rate of flashing indicators approximately 4 per second with time on and time off about equal?

69. Is the immediate surround of indicator lights black?

70. Do the indicator lights have non-glare translucent covering?

71. Is the printed information on indicator light black against a bright background?

72. When vision is required for low illumination conditions, does printed information on indicator lights have the lettering perforated through a black background?

C. Counters

73. Are counters used for reading exact numerical values when there is no need for check reading, setting in values, or determining rate or direction of change, and the number of values is over 100?

74. Are counters mounted close to the panel so that the numbers are not obscured by the panel opening?

75. Is the horizontal spacing between numbers on a counter less than the width of the widest number?

✓	
✓	
✓	
✓	
N	A
N	A
N	A
N	A
✓	
✓	
✓	
✓	
✓	

76. Do the numbers snap into place on the counter type indicator?
77. Does an upward movement of the counter indicate a numerical increase?
78. Does the counter read from left to right?
79. For consecutive reading of counters, do the numbers follow each other with a maximum rate of 2 per second?
80. Is the numerical progression of numbers upward for increase on counters?

IV. Panel Layout

A. General

81. Are the displays and controls laid out according to their expected or required order of operation, following a left-to-right top-to-bottom ordering?
82. Are instruments that are used together grouped together?
83. Is information presented to a single operator presented in the most logical location?
84. If operated by one operator, are controls and indicators required for the operation of a given system contained on a single panel, or on panels in juxtaposition?
85. Are different functional groups of controls and displays arranged on different spatial panels?
86. Is crowding of controls and displays avoided?
87. Are all features of display and control compatible with natural habit patterns of the population of operators?
88. When there are lights in close proximity to an emergency light, does the emergency light have a more prominent configuration?

B. Displays

89. Is information relative to a given operational phase presented in a single visual area?

✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	
N	A
✓	

90. Are critical warning lights located near the center of the visual area?
91. Are warning lights mounted within 30° of the visual axis?
92. Are all displays readable from the normal head position of the operator?
93. Is similarity of display scales and their interpretation maintained as much as possible?
94. Are displays mounted as nearly perpendicular to the line of sight as possible?
95. Are displays located within 30° of the operator's perpendicular line of sight?
96. Are the displays within normal visual range (13" to 28")?

C. Controls

97. Are controls having similar functions manipulated in the same direction to produce the same effect?
98. Are controls separated and located so that accidental manipulation is held at a minimum?
99. Are infrequently used controls or controls used only for maintenance covered if on the external panel and separated from regular operating controls?
100. Are controls separated by 6 to 8 inches when possible?
101. Are frequently used controls mounted forward, between elbow and shoulder height, off-center in line with arm plane, and near normal working position?
102. Are often used controls placed somewhere between elbow and shoulder height?
103. Are controls within 28 inches of the operator's shoulder?
104. Is priority of position given to controls in terms of their importance, frequency of use and speed of manipulation required?

N	A
N	A
✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	
N	A
	✓
✓	
✓	
✓	

105. Are successive control movements inter-related so that one movement passes easily into the next?

V. Functional & Operational Considerations

106. Is the completion of an automatic sequence indicated when it requires an action on the part of the observer.
107. When the operator must wait for an automatic sequencing to finish, does he have an indication that the sequencing is occurring?
108. When equipment warm-up is required before the operator can start operations, is there an indication when the equipment is warmed up?
109. When the operator is required to wait more than 10 seconds between indications, is there an indicator light that shows the equipment is working?
110. Is an auditory signal used in place of or in addition to a light, as an attention getting device in a critical situation, except when the operator's field of vision and attention is by necessity focused in the immediate area of the light at all times that the light may come on?
111. In a critical situation, is an auditory signal given when the operator's attention is required when there is an indefinite wait period prior to the operation?
112. Is the setting up of pre-operation conditions indicated so that operations will not begin prematurely?
113. Does the operating procedure for the equipment include a light check?
114. Is the operator free from requirements for making time estimates?
115. Is automatic sequencing used only when no manual operations are required?
116. Are unfavorable conditions corrected or alleviated automatically where feasible?

✓	
✓	
N	A
N	A
N	A
N	A
✓	
✓	
✓	
✓	
✓	
✓	

117. Is the equipment mounted so that vibration of visual displays is minimized?

118. Are all inputs put into the system by the operator indicated?

VI. General Control & Display Considerations

119. Are unique controls and displays used only when they are known to give improved operator performance?

120. Are controls and displays used for the same functions as other equipments of the system the same?

121. Are controls and displays that are standard among other equipments used on this equipment?

122. Are instruments that are functionally similar, structurally and operationally similar?

123. Are the displays and controls the same as those common among other systems?

124. Are the controls and displays of the equipment or system, structural and functionally similar?

125. Is standardization or sameness used on multiple instrument displays?

126. Are uniform controls used for similar purposes?

VII. Work Area Layout

127. Are objects to be viewed at least 13 inches from the operator's eyes?

128. Are glossy surfaces and highly polished metals avoided?

129. Are physical hazards within the work area and movement area of the operator avoided?

VIII. Illumination

130. Are the indicators illuminated so that the ratio of the brightest to dimmest is less than 7 to 1?

✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	

131. On important indicator lights is the maximum possible dimming still readily visible?

✓

132. Can all indicator lights be seen when maximum dimming is imposed?

✓

133. Is bulb brightness clearly visible in indicator lights?

✓

134. Are the indicator lights bright enough for the task at hand?

✓

135. Is glare from the light source absent on indicated lights?

✓

136. Is the background a dull finish and dark in contrast to the light?

✓

137. Are lights which must attract immediate attention at least twice as bright as the immediate background?

✓

138. Are red lights used where dark adaptation is necessary?

✓

139. Are the displays evenly illuminated?

✓

140. Do the instrument markings have a continuously controllable brightness range from .02 to 1.0 foot lamberts for night flying conditions?

✓

141. Is the brightness of the surrounding area less than the visual task and at least 1/10 the brightness of the visual task?

✓

142. Is a control provided to vary the brightness of indicators when the ambient illumination will vary?

✓

143. If dark adaptation is not required, is the instrument lighting white flood lighting with a brightness range of the markings from 1 to 20 foot lamberts?

✓

144. Is flood lighting used for dial type indicators?

N

A

IX. Labeling

145. Are all control and indicator labels consistent in meaning, i.e., do they all describe a condition, or do they all tell the operator to do something?

✓

163. Are the abbreviations used standard and familiar to the expected operator?
164. Are the labels durable?
165. Do all control and display labels use the same letter size?
166. Are the labels indicating functional groups clearly larger than the control and display labels?
167. Is the height of the numbers and letters $1/10$ to $1/5$ inch for a viewing distance of a maximum of 28 inches?
168. Do white letters on a black background have a stroke width of $1/7$ to $1/8$ the height of the letters?
169. Do black letters on a white background have a stroke width $1/6$ the height of the letters?
170. Does the number and letter design have simple configuration: contain no flourishes, have even stroke width, have vertical strokes of 90° and diagonal ones of 45° , have breaks and openings that are readily apparent?
171. Is the height-width ratio of numbers and letters 3 to 2, except on spherical surfaces such as counters?
172. Is the height-width ratio of numbers on counters 1 to 1?
173. Are labels illuminated so that the ratio of the brightest to dimmest is less than 7 to 1?
174. Are the labels easily read under the expected levels of illumination and viewing distances?
175. Are the labels clearly separated from each other?
176. Are the labels oriented horizontally?
177. Can the labels be seen clearly from expected viewing angles?

✓	
✓	
✓	
✓	
✓	
✓	
✓	
N	A
✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	

178. Is the location of labels in relation to control or display consistent?
179. Are the labels directly above or below the control or display?
180. Are the labels clearly separated from unassociated controls and displays?

X. Control - Display Relationships

181. Are the controls directly under the displays they affect?
182. Are unrelated controls and displays spatially unrelated?
183. Is color coding used to relate associated controls and displays not otherwise related?
184. Do only associated controls and displays use the same color coding?
185. Is marked outline or boxing used to relate associated controls and displays?
186. Does the movement on a display correspond in direction with the movement of its control?
187. Are control movements in the same direction as the resulting display movement?
188. Is the seeing of a display free from interference from the manipulation of a control?
189. When setting information into the equipment, do changes in the display indicate the manipulation of the control without lag?
190. Does a small change in control movement result in a small change in display movement?
191. When fine adjustments are required, does a large movement of the control result in a small movement on the display?
192. Is an indicator light associated with a given switch in juxtaposition to the switch position that affects the light?

✓	
✓	
✓	
✓	
N	A
N	A
✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	
✓	
N	A

8. Interpretation of results and findings.

An analysis and evaluation of the prototype Navigation Control Panel has been performed (Phase I). Based on the results of this investigation, a new configuration for the Nav-Panel has been developed (Phase II). This redesign has been analyzed and evaluated using the same methodologies employed on the prototype design (Phase III). A résumé of the results and findings of these analyses is presented.

8.1 Evaluation of Navigation Control Panel Prototype No. 1

The results of the analyses indicate that this design can perform the specified functions. Communication between the pilot and Navigation Computer is effected by this Nav-Panel. The human engineering aspects, however, have been found to be deficient in several areas. The operator is burdened with an excess of controls and indicators. The method of control manipulation is not clearly indicated from the arrangement and labeling incorporated. Proper grouping of controls used in performing sequential operations also is lacking. In addition, certain controls are not visible to the operator.

8.2 Evaluation of the Redesigned Navigation Control Panel

The results of the analyses conducted on the redesigned panel indicate that it can fulfill the mission of the Navigation Control Panel. There are no major human engineering deficiencies in its design. The

design objective of no new logic or electronic circuits has been met. There is the necessary redesign of the Nav-Panel interlock and illumination circuits, but the Navigation Computer inputs and outputs have been unaltered.

8.3 Comparison of the Navigation Control Panel Designs

A comparison of the original and redesigned Nav-Panels is now in order. This comparison indicates the improvement in design obtained by use of the three analysis techniques.

a. The prototype design employed 17 nixie tubes and 16 push buttons, which virtually filled the available panel face area. The redesign, while still performing the same function as the prototype, employs 10 nixie tubes, 10 push buttons, and an additional data entry counter.

b. The placement of the controls and indicators on the redesigned panel provides complete visibility of all devices. In the prototype design, four push buttons were obscured by use of prisms.

c. The eight data entry push buttons of the prototype design have been replaced by two. This feature was made possible by the addition of a second counter and employing six wheels on each counter. The combining of the data entry push button functions provides a more efficient use of these push buttons. The operator is no longer required to scan eight push buttons and select one to complete a data entry operation. There are only two data entry push buttons and both (in normal entry operations) are pressed in sequence.

d. The use of two data entry counters provides the normal left-to-right, top-to-bottom ordering of the data entry tasks not possible in the prototype design.

e. An additional feature, obtained with the use of two counters, is complete setup of data to be entered prior to execution to the "enter" operation. In the prototype design it was necessary to set the single counter twice to complete an entry. With a counter available for both parts of a quantity to be entered, the operator is now able to preset the counters to display a specified quantity and then perform selection and enter the data at some future time. Thus the time consuming task of counter wheel setting can be performed at the discretion of the operator.

f. The grouping of controls on the redesigned panel is more consistent with their use than the prototype design. A more liberal use of labeling and boxing is employed to indicate associated controls and their functions. In addition, the redesigned Nav-Panel employs selective lighting of the data entry counter wheels to indicate to the operator their use.

g. While not specifically set down as an objective of this study, a considerable cost savings is realized by the redesigned panel. Each nixie tube and its associated grid control circuits cost in excess of \$500. By removing seven nixie tubes, a cost reduction of approximately \$3,500 is effected. The additional counter cost is offset by the removal of six push buttons and their switches.

9. Conclusions

Through the use of human engineering methodologies a man-machine sub-system has been analyzed, evaluated, and redesigned. An analysis of the redesign has shown the superiority of the new model. The redesign may have been arrived at by methods classified as intuition (hunches or guesses) or trial and error procedures. but reasonable or desirable results could not have been anticipated by these methods. The methodologies employed have produced a superior design through systematic techniques. Very little has been left to chance or the intuition of the designer. The redesign has been arrived at by use of analysis methods designed to point out each specific deficiency and tailored to indicate when a near optimum relationship between the man and the machine has been obtained. Due consideration has been given to both man and the machine in that the operator's tasks of data entry have been eased and the machine display functions have been reduced. Emphasis, however, has been focused on the man-machine relationship to the improvement of the sub-system as a whole.

Through the use of human engineering methodologies, proposed or actual man-machine systems may be analyzed and evaluated. There are countless machines, for instance, in the military category that exist today as examples of poor design in as much as the human component is not given a proper chance to operate within his limitations. One has merely to look at the World War II radio transmitters and present day radars on many Navy ships to realize the need for considering the human component. Military electronics is producing machines of uncomprehensible complexity. The concepts of integrated weapons and detection systems controlled by special purpose computers is a reality.

Man is part of these integrated systems. As important to the success of these systems as their electronic and engineering design may be, the human element is as important. If the human element cannot effectively control his machines, how useful are these engineering marvels?

10. Recommendations and suggestions for further research

This section is sub-divided into three parts, each discussing different phases of recommended future investigations or suggestions for further study.

10.1 Recommendations concerning the Navigation Control Panel design

During the course of the study presented, considerable difficulty was encountered with the numerical displays. The nixie tubes presented problems in positioning, due to their internally stacked grid arrangement. The grid control circuits associated with each tube are fairly complicated and bulky; while lightweight in construction, these circuits require relatively large installation space. Other types of numerical displays considered proved to be deficient for various reasons. These deficiencies included weight, inability to meet night and day visibility specifications, and volume requirements.

It is recommended that studies be conducted to provide numerical display devices to meet the following specifications:

- a. Coplanar numerical display of at least five decimal digits, and provisions to add additional digits.
- b. Operation from binary inputs, preferably of a parallel nature.
- c. Compact to a degree, such that, the physical size is determined by the displayed figures, and not the associated circuitry.
- d. Self contained, in that the binary inputs are fed directly to the display unit.

- . A self storing feature such that once energized to display a numerical quantity, the input signal may be removed and the displayed figures will remain displayed until a new input is received.

The applications of such a device are numerous; many military instruments of present and future weapons systems, as well as industrial control and computing machines, are in need of this type of numerical display.

10.2 Recommendations concerning use of presently available human engineering analysis and evaluation techniques.

The effectiveness of the Tentative Operational Procedures Chart has been demonstrated in the redesign of the Navigation Control Panel. Construction of the TOPC was based on the envisioned (tentative) operator use of the controls and displays of the panel. Based on these anticipated operator procedures the panel was redesigned. It is evident that if the panel is operated as envisioned, a near optimum design has been realized. In far too many cases equipment operation in the field is not as the designer had intended it. When the field operator modified the envisioned operational procedures of the designer the worked for optimum relationship of man and machine is compromised.

It is recommended that a completed TOPC (first three columns only) or similar document accompany the completed Navigation Control Panel into the field. After a sufficient period of operational time, the operator procedures sections should be corrected to indicate actual field operation of the equipment. This corrected document should then be returned to the designer. By studying the actual operator procedures, the designer will be able to improve the design

on future and replacement equipment. A procedure such as this will provide a means of "operator-to-designer feedback", permitting more nearly optimum machine system designs.¹

10.3 Suggestions for further research in the field of analysis and evaluation techniques.

It is apparent from the foregoing work that the presently available human engineering methodologies have reached a sufficient level of sophistication to provide investigators with usable "tools" of analysis. The three techniques employed by the author require an appreciable amount of time and labor in their application. Some of the other available methods (discussed in Section 2) are even more involved and time consuming. With due consideration of the work required to employ these human engineering methodologies, they do produce valuable results. The results are of sufficient merit to recommend that such techniques be employed by all designers of equipment for use by human operators. However, to more quickly realize this goal, the methodologies must be made more "usable." It is recommended that studies be conducted to reduce the methodological techniques of man-machine analysis to simpler and faster procedures, and these revised methods made available to equipment and system designers. The designer will then be more willing and able to incorporate these procedures into his design.

¹ Under some existing hardware contracts this is done as part of a job analysis.

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APPENDIX A

FUNCTIONAL DESCRIPTION OF THE CONTROLS AND INDICATORS OF THE NAVIGATION CONTROL PANEL PROTOTYPE NO. 1

The following functional description consists of the first twelve pages of a Litton Industries' document. Only those pages used by the author in preparing the prototype design TOPC have been included. Reference to the "Navigation Mode and Doppler Control" and "Inertial Control" panels should be ignored; they are adjacently mounted panels and of no concern in the present study. The Navigation Control Panel section of Figure 1 referred to in the introductory paragraph is reproduced following the functional description.

Functional Description of the Controls and Indicators for the W2F-1 Navigation Control Panels

The W2F-1 navigation controls and indicators operated by the pilot and/or co-pilot are mounted on three edge-lighted panels located at the center-line of the aircraft on the forward section of the control pedestal. The three panels are the: (1) Navigation Control, (2) (2) Navigation Mode and Doppler Control, and (3) Inertial Control Panels. The preliminary layout of the panels is shown in Figure 1, and the description of each control and indicator follows:

I. NAV CONTROL Panel

1. Degrees ($^{\circ}$). This is a three-in-line Nixie tube readout and an associated degree mark ($^{\circ}$) etched in the edge-lighted panel. The Nixies and degree mark are used in conjunction with the TRACK, DESTINATION, REF PT TO BAR., and WIND switches to display ground track angle, bearing to destination, bearing from barrier reference point to barrier center, or wind direction, depending upon which one of the four switches is activated. The degree mark ($^{\circ}$) is visible at all times and is illuminated whenever the panel is lighted. The Nixie tubes are only active when one of the four switches above is actuated.

Note: All bearings or directions displayed in this readout are in degrees true.

2. **KNOTS -- MILES.** This is a three-in-line Nixie tube readout and associated back-lighted split indicator used in conjunction with the **TRACK**, **DESTINATION**, **REF PT TO BAR.**, and **WIND** switches to display ground velocity in knots, range to destination in nautical miles, range from barrier reference point to barrier center in nautical miles, and wind speed in knots, depending upon which one of the four switches is activated. When ground velocity or wind speed is being displayed numerically in the Nixie readouts only the **KNOTS** portion of the split indicator is illuminated and that legend becomes legible. When the range to destination or range from barrier reference point to barrier center is displayed in the readout only the **MILES** portion of the indicator is illuminated and that legend becomes legible.
3. **TRACK.** This is a momentary contact push-button switch which is electrically interlocked with **DESTINATION**, **REF PT TO BAR.**, and **WIND** switches. When this switch is activated its push-button cap illuminates, the **KNOTS** portion of the **KNOTS -- MILES** indicator illuminates, and the **W2F-1's** ground track angle and ground speed are displayed in the Nixie readouts. The displayed information is updated as new information becomes available. If no track information is available in the computer, the Nixies will display zeros. If the **DESTINATION**, **REF PT TO BAR.**, or **WIND** switch cap is illuminated, activation of the **TRACK** switch extinguishes the illuminated push button and associated indicators and changes the data displayed in the readout to ground track angle ($^{\circ}$) and ground velocity (**KNOTS**).

When the TRACK switch is activated its switch cap will remain illuminated and its associated data will be displayed until one of the other three switches is activated or the TRACK switch is reactivated. Activation of the TRACK switch when it is illuminated, extinguishes its push-button light and its associated indicator and Nixie readouts.

4. DESTINATION. This is a momentary contact push-button switch which is electrically interlocked with the TRACK, REF PT TO BAR., and WIND switches. When this switch is activated its push-button cap illuminates, the MILES portion of the KNOTS -- MILES indicator illuminates, and the ^{TRUE}~~relative~~ bearing and range from the W2F-1 to its destination are displayed in the Nixie readouts. The displayed information is updated as new information becomes available. If no destination bearing and range information exists in the computer, the Nixies will display zeros. If the TRACK, REF PT TO BAR., or WIND switch cap is illuminated, activation of the DESTINATION switch extinguishes the illuminated push button and associated indicators and changes the data displayed in the readouts to bearing ($^{\circ}$) and range (MILES) to destination. When the DESTINATION switch has been activated its switch cap will remain illuminated and its associated data will be displayed until one of the other three switches is activated or the DESTINATION switch is reactivated. Activation of the DESTINATION switch when it is illuminated extinguishes its push-button light and its associated indicator and Nixie readouts.

5. REF PT TO BAR.. This is a momentary contact push-button switch which is electrically interlocked with the TRACK, DESTINATION, and WIND switches. When this switch is activated its push-button cap illuminates, the MILES portion of the KNOTS -- MILES indicator illuminates, and the bearing and range from the barrier reference point to the barrier center are displayed in the Nixie readouts. The displayed information is updated as new information becomes available. If no reference point to barrier information exists in the computer, the Nixies will display zeros. If the TRACK, DESTINATION, or WIND switch cap is illuminated, activation of the REF PT TO BAR. switch extinguishes the illuminated push button and associated indicators and changes the data displayed in the readouts to bearing ($^{\circ}$) and range (MILES) from barrier reference point to barrier center. When the REF PT TO BAR. switch has been activated its switch cap will remain illuminated and its associated data will be displayed until one of the other three switches is activated or the REF PT TO BAR. switch is reactivated. Activation of the REF PT TO BAR. switch when it is illuminated, extinguishes its push-button light and its associated indicator and Nixie readouts.
6. WIND. This is a momentary contact push-button switch which is electrically interlocked with the TRACK, DESTINATION, and REF PT TO BAR. switches. When this switch is activated its push-button cap illuminates, the KNOTS portion of the KNOTS -- MILES indicator illuminates, and the wind direction and speed are displayed in the Nixie readouts. The displayed information is updated as new

information becomes available. If no wind information exists in the computer, the Nixies will display zeros. If the TRACK, DESTINATION, or REF PT TO BAR. switch cap is illuminated, activation of the WIND switch extinguishes the illuminated push button and associated indicators and changes the data displayed in the readouts to wind direction ($^{\circ}$) and speed (KNOTS). When the WIND switch has been activated its switch cap will remain illuminated and its associated data will be displayed until one of the other three switches is activated or the WIND switch is reactivated. Activation of the WIND switch when it is illuminated, extinguishes its push-button light and its associated indicator and Nixie readouts.

7. Latitude. This is a five-in-line Nixie tube readout which displays latitude in degrees and minutes north or south. The readout operates in conjunction with the POSIT, DESTINATION, and REF PT switches immediately below it to display the latitude of the W2F-1's present position, destination, or the barrier reference point, depending on which of the three switches is activated. The two Nixie tubes on the left display degrees of latitude, the next two display minutes and the rightmost Nixie tube displays N or S for North or South.

8. Longitude. This is a six-in-line Nixie tube readout which displays longitude in degrees and minutes east or west. The readout operates in conjunction with the POSIT, DESTINATION, and REF PT switches immediately below it to display the longitude of the W2F-1's present

position, destination, or the barrier reference point, depending on which of the three switches is activated. The three Nixie tubes on the left display degrees of longitude, the next two display minutes of longitude and the rightmost Nixie tube displays E or W for East or West.

9. POSIT. This is a momentary contact push-button switch which is electrically interlocked with the DESTINATION and REF PT (latitude and longitude) switches. When this switch is activated its push-button cap illuminates and the latitude and longitude of the W2F-1's present position are displayed in the Latitude and Longitude readouts immediately above it. If the present latitude and/or longitude values do not exist in the computer, the Nixies will display zeros. The displayed data is updated as new information becomes available. If the DESTINATION or REF PT switch cap is illuminated, activation of the POSIT switch extinguishes the illuminated push button and changes the data displayed in the readouts to the W2F-1's present position latitude and longitude. When the POSIT switch has been activated, its switch cap will remain illuminated and its associated data will be displayed in the readouts until the DESTINATION or REF PT switch is activated or the POSIT switch is reactivated. Activation of the POSIT switch when it is illuminated extinguishes its push-button light and the associated Nixie readout.

10. DESTINATION. This is a momentary contact push-button switch which is electrically interlocked with the POSIT and REF PT switches. When this switch is activated its push-button cap illuminates and the latitude and longitude of the W2F-1's destination are displayed in the Latitude and Longitude readouts immediately above it. If the destination latitude and/or longitude values do not exist in the computer, the Nixies will display zeros. The displayed data is updated as new information becomes available through manual entry as described in paragraphs 19 through 22 below. If the POSIT or REF PT switch cap is illuminated, activation of the DESTINATION switch extinguishes the illuminated push button and changes the data displayed in the readouts to the latitude and longitude of the W2F-1's destination. When the DESTINATION switch has been activated, its switch cap will remain illuminated and its associated data will be displayed in the readouts until the POSIT or REF PT switch is activated or the DESTINATION switch is reactivated. Activation of the DESTINATION switch when it is illuminated extinguishes its push-button light and the associated Nixie readouts.

11. REF PT. This is a momentary contact push-button switch which is electrically interlocked with the POSIT and DESTINATION switches. When this switch is activated, its push-button cap illuminates and the latitude and longitude of the W2F-1's barrier reference point are displayed in the Latitude and Longitude readouts immediately above it. If the barrier reference point latitude and/or longitude values do not exist in the computer, the Nixies will display zeros.

These values may be entered into the computer either manually in latitude and longitude terms as described in paragraphs 19 through 22 below, or in x,y terms on an indicator unit in the CIC compartment by hooking and designating a target on the CRT display as the barrier reference point. The displayed data is updated as new information becomes available. If the POSIT or DESTINATION switch cap is illuminated, activation of the REF PT switch extinguishes the illuminated push button and changes the data displayed in the readouts to the latitude and longitude of the barrier reference point. When the REF PT switch has been activated its switch cap will remain illuminated and its associated data will be displayed in the readouts until the POSIT or DESTINATION switch is activated or the REF PT switch is reactivated. Activation of the REF PT switch when it is illuminated extinguishes its push-button light and the associated Nixie readouts.

Note: In addition to their display functions described above, the POSIT, DESTINATION, and REF PT switches are used in conjunction with the DATA ENTRY counter and LAT N, LAT S, LONG E, and LONG W switches to enter manually the latitude and longitude of the W2F-1's present position, destination, and the barrier reference point as described in paragraphs 19 through 22 below.

12. LIGHT TEST. This is a momentary contact push-button switch which is used to check the functioning of all light bulbs in the indicators and switches on the Nav Control and Nav Mode panels. When this switch

is activated all functioning light bulbs will illuminate. When the push button is released, the illuminated readouts and light bulbs will be extinguished^d (except those that were illuminated before the light test was initiated).

13. COUNTER BRIGHTNESS. This is a continuous rotary control which is used to adjust the brightness of the Nixie tube readouts. Clockwise rotation of the control brightens the readouts. Full counterclockwise rotation of the control adjusts brightness to a minimum consistent with even illumination of the entire digit and full clockwise rotation adjusts brightness to a maximum.

14. DATA ENTRY. This five-in-line manually operated counter is used in conjunction with the BRG -- REF PT TO BAR., RANGE -- REF PT TO BAR., WIND DIR, WIND SPEED, LAT N, LAT S, LONG E, and LONG W and with the POST, DESTINATION, and REF PT switches to enter data into or to change data in the navigation computer. The data to be entered into the computer will be set in the 5 wheel counter in the following manner: 1) the numerical values for range, bearing, or speed will be set into the three wheels to the left in the counter (the two wheels on the right are used only for entry of "minutes" of latitude or longitude); 2) the latitude and longitude values are set in the counter so that the minutes are represented by the values in the two right wheels and the degrees are represented by the values in the three left wheels.

Data on the bearing or range from barrier reference point to barrier center, or wind direction or speed are entered by setting the numerical value into the counter and then activating the appropriate switch.

Data on latitude and longitude of a point is entered by first activating one of the latitude-longitude switches labeled POSIT, DESTINATION, or REF PT, then entering the numerical value into the counter, and then activating one of the switches labeled LAT N, LAT S, LONG E, or LONG W to enter the latitude or longitude of the W2F-1's present position, destination, or barrier reference point into the computer.

15. BRG -- REF PT TO BAR.. This is a momentary contact push-button switch which is used to enter the bearing from the barrier reference point to barrier center into the computer. When this switch is activated it causes the values set in the three left-hand wheels of the DATA ENTRY counter to be entered into the navigation computer as the bearing in degrees from the barrier reference point to the barrier center.

16. RANGE -- REF PT TO BAR.. This is a momentary contact push-button switch which is used to enter the range from the barrier reference point to the barrier center into the computer. When this switch is activated it causes the value set in the three left-hand wheels of the DATA ENTRY counter to be entered into the navigation computer as the range in nautical miles from the barrier reference point to the barrier center.

17. WIND DIR. This is a momentary contact push-button switch which is used to enter the wind direction into the computer. When this switch is activated it causes the value set in the three left-hand wheels of the DATA ENTRY counter to be entered in the navigation computer as the direction from which the wind is proceeding in degrees (referenced to True North).
18. WIND SPEED. This is a momentary contact push-button switch which is used to enter the wind speed into the computer. When this switch is activated it causes the value set in the three left-hand wheels of the DATA ENTRY counter to be entered in the navigation computer as the current speed of the wind in knots.
19. LAT N. This is a momentary contact push-button switch which is used to enter the north latitude of a point in degrees and minutes into the computer. If the push-button cap of the POSIT, DESTINATION, or REF PT switch is illuminated and a numerical value is set in the DATA ENTRY counter, activation of the LAT N switch causes the numerical value in the counter to be recorded in the computer as the north latitude of the point designated by the illuminated POSIT, DESTINATION, or REF PT switch. This entered value will appear in the Latitude (N) Nixie readout.
20. LAT S. This is a momentary contact push-button switch which is used to enter into the navigation computer the south latitude of a point in degrees and minutes. If the push-button cap of the POSIT,

DESTINATION, or REF PT switch is illuminated and a numerical value is set in the DATA ENTRY counter, activation of the LAT S switch causes the numerical value in the counter to be recorded in the computer as the south latitude of the point designated by the illuminated POSIT, DESTINATION, or REF PT switch. This entered value will appear in the Latitude (S) Nixie readout.

21. LONG E. This is a momentary contact push-button switch which is used to enter into the navigation computer the east longitude of a point in degrees and minutes. If the push-button cap of the POSIT, DESTINATION, or REF PT switch is illuminated and a numerical value is set in the DATA ENTRY counter, activation of the LONG E switch causes the numerical value in the counter to be recorded in the computer as the east longitude of the point designated by the illuminated POSIT, DESTINATION, or REF PT switch. This entered value will appear in the Longitude (E) Nixie readout.

22. LONG W. This is a momentary contact push-button switch which is used to enter into the navigation computer the west longitude of a point in degrees and minutes. If the push-button cap of the POSIT, DESTINATION, or REF PT switch is illuminated and a numerical value is set in the DATA ENTRY counter, activation of the LONG W switch causes the numerical value in the counter to be recorded in the computer as the west longitude of the point designated by the illuminated POSIT, DESTINATION, or REF PT switch. This entered value will appear in the Longitude (W) Nixie readout.

1 4 7 °

2 2 2

KNOTS

 MILES

N

TRACK

DESTINATION

REF PT
TO
BAR

WIND

A
V

5 4 °

2 8 ' N

1 2 1 °

1 4 ' E

C

POSIT

DESTINATION

REF PT

O
N
T
R
O
L

DATA ENTRY

LIGHT
TEST

COUNTER
BRIGHTNESS

BRG
 REF PT
 TO BAR

CHANGE
 REF PT
 TO BAR

WIND
DIR

WIND
SPEED

LAT
N

LAT
E

LONG
E

LONG
W

Figure 16 Navigation Control Panel Prototype No. 1

APPENDIX B

FUNCTIONAL DESCRIPTION OF THE CONTROLS AND INDICATORS FOR THE NAVIGATION CONTROL PANEL REDESIGN

The navigation controls and indicators operated by the pilot are mounted on an edge-lighted panel located to the left of the center-line of the aircraft on the forward section of the control pedestal.

All push-button switch caps on these panels are matte finish black opaque caps with legends and a border around the perimeter of the cap face engraved into a white translucent plastic. Under normal or high ambient illumination the outline of the cap as well as the cap legend is visible as white markings. Under low ambient conditions, the markings are dimly illuminated and are visible as aircraft red markings as are all markings on the edge lighted panels themselves. The intensity of illumination is variable (from an external source).

In the descriptions which follow, when a push-button cap is said to be lighted under "night" conditions, the intensity level to which the cap is lighted is greater than the dim illumination level used for cap and legend identification by a factor of several discriminable differences. Under "day" conditions, the push-button cap is illuminated to a set level which approaches the rated voltage of the lamps.

1. Numerical Displays

Near the top of the Nav Control panel on a section of the panel which is inclined so as to be approximately normal to the pilot's line of sight are located two numerical readout displays. Each

display consists of an "in-line" configuration of five sub-miniature Nixie tubes and an associated back-lighted split indicator on which one of three, or four, legends can be displayed. The two rows of displays are used in conjunction with the seven "Display" and "Enter" push-buttons described below, to display either bearing and range, bearing and speed, or latitude and longitude. Information being displayed in these readouts is updated as new information becomes available from the Navigator Computer.

When bearing and range or bearing and speed are displayed the first three (from the left) nixie tubes, of the upper row illuminate to display the numerical value of bearing and the portion of the split indicator in that row labeled $^{\circ}$ T illuminates indicating that the numerical value represents bearing in degrees true. In the lower row (when range is displayed) the first three nixie tubes display the numerical value of range and that portion of the split indicator labeled MLS illuminates indicating that the numerical value represents range in (nautical) miles. When speed is being displayed, the first three nixies display the numerical value of speed and the portion of the split indicator in that row labeled KTS illuminates indicating that the numerical value represents speed in knots.

When latitude and longitude are displayed, the last four (2nd, 3rd, 4th, and 5th) nixie tubes of the upper row display the

numerical value of latitude and the portion of the split indicator labeled N (or S) illuminates indicating that the numerical value represents degrees and minutes of North (or South) latitude. All five nixie tubes in the second row display the numerical value of longitude and the portion of the split indicator in that row labeled E (or W) illuminates indicating that the numerical value represents degrees and minutes of East (or West) longitude.

When no values have been selected for display all nixie tubes and both back-lighted indicators are unlighted.

If no information exists in the computer for the category selected for display, all nixies will display zeros.

2. DESTINATION BRG & RG.

This is a momentary contact push-button switch which is electrically interlocked with the TRACK, WIND, REF PT TO BAR, POSIT, REF PT, and DESTINATION L & λ switches such that only one of these switches is "on" at one time. When this switch is activated, any of the above six switch caps which was lighted is extinguished, the push-button cap on this switch is illuminated, as long as the cap remains lighted the bearing and range from the W2F-1's present position to the destination is displayed in the two rows of nixies as described in 1 above. If the push button on this switch is illuminated, activation of the switch extinguishes the lighted push-button and clears the two rows of nixies so that all nixies and the two back-lighted indicators are ex-

tinguished.

3. TRACK

This is a momentary contact push-button switch which is electrically interlocked with the DESTINATION BRG & RG, WIND, REF PT TO BAR, POSIT, REF PT, and DEST - L & λ switches such that only one of these switches can be "on" at any one time. When this switch is activated, any of the above six switch caps which was lighted is extinguished, the push-button cap on this switch is illuminated, and the W2F-1's track angle and ground speed are displayed in the two rows of nixies as described in 1 above. The nixie displays remain lighted in this way as long as the push-button cap on this switch is illuminated. Activation of this switch when its cap is lighted extinguishes the push-button lamp, the nixie tubes, and back-lighted indicators.

4. WIND

This is a momentary contact push-button switch which is electrically interlocked with the DEST - BRG & RG, TRACK, REF PT TO BAR, POSIT, REF PT, and DEST - L & λ switches such that only one of these switches can be "on" at any one time. When this switch is activated, any of the above six switch caps which was lighted is extinguished, the push-button cap on this switch is illuminated, the wind direction and speed are displayed in the two rows of nixies as described in 1 above, and the first three (from the left) data entry counter wheels of each counter described in 9 below are lighted. The nixie displays and counters remain lighted in

switches can be "on" at any one time. When this switch is activated, any of the above six switch caps which was lighted is extinguished, the push-button cap on this switch is illuminated, the latitude and longitude of the destination in degrees and minutes are displayed in the two rows of nixies as described in 1 above, and all data entry counter wheels described in 9 below are lighted. The nixie displays and counters remain lighted in this way as long as the push-button cap on this switch is illuminated. Activation of this switch when its cap is lighted extinguishes the push-button lamp, the nixie tubes, back-lighted indicators, and the counters.

Whenever the DEST - L & λ switch cap is illuminated, any numerical entries made by using the data entry counters and the LAT/BRG and LONG/KNOTS/MILES switches described in 9, 10 and 11 below are designated as the latitude or longitude of the destination in degrees and minutes.

9. Data Entry Counters

These two six-in-line manually operated thumb-wheel counters are used in conjunction with the WIND, REF.PT TO BAR, POSIT, REF PT, DESTINATION L & λ and the LAT/BRG and LONG/KNOTS/MILES push-button switches to enter data into or to change data in the navigation computer. The data to be entered into the computer is set in the two counters in the following manner: 1) numerical values for bearing will be set into the three left-hand counter

this way for as long as the push-button cap on this switch is illuminated. Activation of this switch when its cap is lighted extinguishes the push-button, the nixie tubes, back-lighted indicators, and the data entry counters.

Whenever the WIND switch cap is illuminated, any numerical entries made by using the data entry counter wheels and the LAT/BRG and LONG/KNOTS/MILES switches described in 9, 10, and 11 below are designated as wind direction (bearing) and wind speed.

5. REF PT TO BAR

This is a momentary contact push-button switch which is electrically interlocked with the DEST - BRG & RG, TRACK, WIND, POSIT, REF PT, and DEST - L & λ switches such that only one of these switches can be "on" at any one time. When this switch is activated, any of the above six switch caps which was lighted is extinguished, the push-button cap on this switch is illuminated, the bearing and range from barrier reference point to barrier center are displayed in the two rows of nixies as described in 1 above, and the first three (from the left) data entry counter wheels of each counter described in 9 below are lighted. The nixie displays and counters remain lighted in this way for as long as the push-button cap on this switch is illuminated. Activation of this switch when its cap is lighted extinguishes the push-button lamp, the nixie tubes and back-lighted indicators, and the counters.

Whenever the REF PT TO BAR switch cap is illuminated, any numerical entries made by using the data entry counters and the LAT/BRG and LONG/KNOT/MILES switches described in 9, 10 and 11 below are designated as bearing and range from barrier reference point to barrier center.

6. POSIT

This is a momentary contact push-button switch which is electrically interlocked with the DEST - BRG & RG, TRACK, WIND, REF PT TO BAR, REF PT, and DEST - L & λ switches such that only one of these switches can be "on" at any one time. When this switch is activated, any of the above six switch caps which was lighted is extinguished, the push-button cap on this switch is illuminated, the present position of the W2F-1 in degrees and minutes of latitude and longitude are displayed in the two rows of nixies as described in 1 above, and the all data entry counter wheels described in 9 below are lighted. The nixie displays and counters remain lighted in this way for as long as the push-button cap on this switch is illuminated. Activation of this switch when its cap is lighted extinguishes the push-button lamp, the nixie tubes, back-lighted indicators, and the counters.

Whenever the POSI switch cap is illuminated, any numerical entries made by using the data entry counters and the LAT/BRG and LONG/KNOTS/MILES switches described in 9, 10 and 11 below are designated as the W2F-1's present position in degrees and minutes of latitude and longitude.

7. REF PT

This is a momentary contact push-button switch which is electrically interlocked with the DEST - BRG & RG, TRACK, WIND, REF PT TO BAR, POSIT, and DEST - L & λ switches such that only one of these switches can be "on" at any one time. When this switch is activated, any of the above six switch caps which was lighted is extinguished, the push-button cap on this switch is illuminated, and the position of the barrier reference point in degrees and minutes of latitude and longitude are displayed in the two rows of nixies as described in 1 above, and all data entry counter wheels described in 9 below are lighted. The nixie displays and counters remain lighted in this way for as long as the push-button cap on this switch is illuminated. Activation of this switch when its cap is lighted extinguishes the push-button lamp, the nixie tubes, back-lighted indicators, and the counters.

Whenever the REF PT switch cap is illuminated, any numerical entries made by using the data entry counters and the LAT/BRG and LONG/KNOTS/MILES switches described in 9, 10 and 11 below are designated as the latitude or longitude, of the barrier reference point in degrees and minutes.

8. DEST - L & λ

This is a momentary contact push-button switch which is electrically interlocked with the DEST - BRG & RG, TRACK, WIND, REF PT TO BAR, POSIT, and REF PT switches such that only one of these

wheels of the upper counter (the three wheels on the right are used only for the entry of "minutes" of latitude); 2) latitude values are set in the upper counter so that degrees are represented by the values of the second and third wheels, minutes are represented by the values in the fourth and fifth wheels, and the direction of latitude is represented by a letter (N or S) in the sixth wheel; 3) speed and distance will be set into the three left-hand counter wheels of the lower counter; 4) longitude values are set in the lower counter so that degrees are represented by the values of the three left wheels, minutes by the values of the fourth and fifth wheels, and direction of longitude is represented by a letter (E or W) in the sixth wheel.

Each of the first five wheels of both counters can be set to any numerical values 0 through 9 while the right-hand wheels have only two positions, N or S for the upper counter and E or W for the lower counter, one of which must be manually selected to make a latitude or longitude entry. Each wheel is internally lighted according to the settings of the push-button switches as described in 4, 5, 6, 7, and 8 above.

10. LAT/ERG

This is a momentary contact push-button switch which is used to enter numerical data set into the lighted thumb-wheel counters in the computer. If either the WIND or REF PT TO BAR switch is "on" (its push-button cap is illuminated), activation of this switch causes the numbers set into the first three wheels of the

upper counter to be entered into the computer as bearing of the wind or bearing from barrier reference point to barrier center respectively. If either the POSIT or REF PT, or DEST - L & λ switch is "on" (its cap is illuminated), activation of this switch causes the numbers set into the first five counters and the sign (N or S) set into the last counter to be entered into the computer as degrees, minutes, and direction of latitude for the W2F-1 present position, the barrier reference point, or the destination respectively.

11. LONG/KNOTS/MILES

This is a momentary contact push-button switch which is used to enter numerical data set into the lighted wheels of the lower counter in the computer. If the WIND switch is "on" (its push-button cap is illuminated), activation of this switch causes the numbers set into the first three counters to be entered into the computer as speed of the wind. If the REF PT TO BAR switch is "on" (its cap is illuminated), activation of this switch causes the numbers set into the first three counters to be entered into the computer as the range from barrier reference point to barrier center. If either the POSIT, or REF PT, or DEST - L & λ switch is "on" (its cap is illuminated), activation of this switch causes the numbers set into the first five counters and the sign (E or W) into the last counter to be entered into the computer as degrees, minutes, and direction of longitude for the W2F-1 present position, the barrier reference point, or the destination respectively.

12. LIGHT TEST

This is a momentary contact push-button switch which is used to check the functioning of all light bulbs in the indicators and push buttons on the Nav Panel. When this switch is activated all functioning light bulbs will illuminate. When the push-button is released, the illuminated readouts and light bulbs will return to the state which existed prior to initiation of the light test.

13. COUNTER BRIGHTNESS

This is a continuous rotary control which is used to adjust the brightness of the nixie tube readouts. Clockwise rotation of the control brightens the readouts. Full counterclockwise rotation of the control adjusts brightness to a minimum consistent with even illumination of the entire digit and full clockwise rotation adjusts brightness to a maximum.

DESCRIPTION OF PSYCHOLOGICAL PROCESS COLUMN CODING¹

The "Psychological Process" column suggests the psychological processes, broadly conceived, probably involved in the operator procedures described in the second column.

There is some experimental evidence that the categories listed are relatively independent; however, any such categorization of human activity will of necessity include categories which overlap and categories whose boundaries are ill-defined.

The motor and auditory-vocal categories are considered psychological processes to the extent that they require at least a low level of mental activity to direct their functioning.

Code

- A-V Auditory-Vocal Process (refers to the basic hearing and speaking functions only, not the information transmitted or received)
- M Motor-Processes (intelligence factor minimal)
- M1 Wrist finger speed (as in tapping, ballistic movement)
- M2 Finger dexterity (as in manipulating pegs and pins, in making fine dial adjustments)
- M3 Rate of arm movement (as in moving from a switch on the left side of the console to a switch on the right side)
- M4 Manual dexterity (more gross hand operations, as in grasping, turning a detented knob)
- M5 Two-hand coordination

¹ From Litton Industries Technical Proposal to the Department of the Navy, Office of Naval Research for "A Study of Man-Machine Integration in Future Anti-Ballistic Missile Systems; Enclosure 3, pp. A-19, A-20; 27 April 1959.

- M6 Arm-hand steadiness
- M7 Hand-foot coordination
- M8 Eye-hand coordination (as in aiming, positioning pencil probe)
- M9 Motor kinesthesia (body or body member adjustment without visual cues, as in "feeling" hooking foot-switch activate)
- M10 Psychomotor coordination (as in rotary pursuit, operating rudder and joystick controls)
- M11 Psychomotor speed
- M12 Spatial-motor relations (as in using the slew control to offset the display)
- M13 Reaction time (simple or complex, as releasing a switch)
- P Perceptual Processes (sensory awareness plus discrimination among stimuli)
- P1 Brightness discrimination (detect differences in brightness, threshold level, and flicker)
- P2 Color discrimination
- P3 Visual shape and form discrimination
- P4 Visual size discrimination
- P5 Visual acuity (all three kinds: minimum separable - two dots or lines distinguished from each other; minimum visible - detection of smallest dot possible; vernier - detection of smallest possible separation of two segments of a broken line)
- P6 Visual space perception (location in two-dimensional or three-dimensional space)
- P7 Visual movement perception
- P8 Visual perceptual speed (as in finding a given object among distractors which do not have strong gestalt properties)
- P9 Proprioceptive (kinesthetic space location, as in reaching for a knob without looking at it)
- P10 Tactual (as in distinguishing among knobs from their shape)

C Cognitive Processes (involves the higher mental processes,
discernment of meaning)

C1 Information

C2 Memory

C3 Deduction (as in analyzing, abstracting, inferring, retaining a figure in a distracting field; flexibility of closure)

C4 Induction (as in categorizing, unifying a relatively unstructured field, developing generalities from specificities; speed of closure)

C5 Invention (inventive thinking involving past experience plus present perceptual experiences plus creative effort)

C6 Decision (simple or complex, involving a consideration of the probability of occurrence of alternative outcomes and of the value -- costs or payoffs -- placed on alternative outcomes; choice)

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